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DEPARTMENT OF ENERGY, MINES AND RESOURCES MINES BRANCH OTTAWA

Mines Branch Research Program on Environmental Improvement

MINES BRANCH SEMINAR ON ENVIRONMENTAL IMPROVEMENT

by

THE STAFF

Report ADM 70-1

January, 1970

CONTENTS

1. Agenda - 1

2. Mines Branch Research on Environmental Improvement 2
2.1. Research on Combustion - Source Pollution at CCRL - 3
2.2. Fuels Research Centre Program - 7
2.2.1. Introduction - 7
2.2.2. Pollution in Various Regions of the Atmosphere - 8
2.2.3. Mine Air - 9
2.2.4. Atmosphere Pollution in Major Centres of Population 10
2.2.5. Pollution in the Upper Atmosphere - 13
2.2.6. Explosive Atmospheres Research - 14
2.2.7. Research on Oil Refining - 16
2.2.7.1. Introduction - 16
2.2.7.2. Air Pollutants From Oil Refineries - 17
2.2.7.3. Water Pollution From Oil Refineries - 23
2.2.8. Contribution to Pollution Abatement by Fuels Research Centre - 26
2.3. Research on Mine Atmosphere - 29
2.3.1. Respirable Dust Hazard in Mines - 29
2.3.2. Environmental Control Group, Mining Research Centre 31
2.3.3. Mine Environmental Control Program - 32
2.3.4. Trends in Mining Research - 35
2.4. Research on Mineral Processing - 37
2.4.1. Crushing Operations in Metal Mines - 37
2.4.2. Comminution of Non-Metallic Minerals - 40
2.4.3. Calcination - 40
2.5. Research on Hydrometallurgy - 42
2.6. Research on Physical Metallurgy - 45
2.6.1. Ferrous Foundry Pollution - 46
2.6.2. Air Pollution in Steelworks - 48
2.6.3. Non-Ferrous Metals - 51
2.7. Research on Metallurgical Coke - 57
2.7.1. Metallurgical Coke and Air Pollution - 57
2.7.2. The Removal of Pyrite from Coal - 62
2.7.3. The Mechanical Dewatering of Coal - 63
2.7.4. Need for New Coking Processes - 63
2.7.5. Air Pollution and Capital Requirements - 64
2.8. Research on Pyrometallurgy - 67
2.8.1. Introduction - 67
2.8.2. Dust - 68
2.8.3. Fume - 69
2.8.4. Poisonous Gases - 71
2.8.5. Detection Methods - 71
2.8.6. Collection Equipment for Dust and Fume - 74
2.8.7. Collection of Sulphur Dioxide - 75
2.8.8. General Comments - 75
2.8.9. Conclusion - 76
2.8.10. References - 77
2.9. Analytical Facilities - Mines Branch - 81
2.9.1. Mineral Sciences Division Services - 81
2.9.2. Identification of Particulate Matter - 85
2.9.3. Gas Analysis Facilities at FRC - 88

3. Ambient Air Quality Objectives - 90

1. Agenda as modified by written contributions:

1.1 January 8, 1970. Corkstown Road - Bldg. 3.

9.00 a.m. Opening Remarks by A. Ignatieff
9.10 a.m. Chairman's Remarks - E.R. Mitchell
9.15 a.m. Research on Combustion Source Pollution - G.K. Lee
Report of the Fuels Research Centre

1) Fuel Conversion - Dr. D.S. Montgomery
2) Explosive Atmospheres - G.K. Brown
3) Oil refining - F.L. Booth

1.30 p.m. Report of the Mining Research Centre

1) Research on mine atmosphere - T.S. Cochrane
2) Respirable dust hazard - T.S. Cochrane

1.2 January 9, 1970. Conference Room - 555 Booth St.

9.00 a.m. Director's Remarks - Dr. John Convey
9.10 a.m. Research on Mineral Processing - D.E. Pickett
Research on Hydrometallurgy - Dr. K.W. Downes
Dr. T.R. Ingraham
Research on Physical Metallurgy - S.L. Gertsman
J.O. Edwards
R.K. Buhr
Dr. R.L. Cunningham
Research on Metallurgical Coke - J.C. Botham
Dr. J. Walsh
Research on Pyrometallurgy - G. Viens
G.N. Banks
Analytical Facilities

1) Mineral Sciences Services - V.A. Haw
2) Fuels Research Centre - R.G. Draper

Ambient Air Quality Objectives - E.R. Mitchell
F.T. Rabbitts

Noon Discussion on the suitability of the project title and a format for the proceedings report of the seminar.

1.00 p.m. Adjourned

2. Mines Branch Research on Environmental Improvement

The Mines Branch has been collecting data and conducting research related to the quality of the environment for many years. It is this systematic investigation that provides the basis for planning, development, and management of our air resources.

Mines Branch contribution to pollution abatement

The Branch's research effort on the control of combustion-source air pollution has been described in Information Circular IC 211, "Air Pollution: Causes and Control" (1968). A considerable number of other reports has also been issued dealing with specific aspects of air quality control and improvement. In addition, in June, 1969, an inventory was compiled of current research on environmental improvement (Internal Report ADM 69-2, "The Role of the Mines Branch in Pollution Abatement and Environmental Control"). This report contains summaries of the research projects being carried out in the Branch in the fields of combustion, fuel processing, mineral and metal processing, and mining.

Seminar on environmental improvement

On January 8 - 9, 1970, an informal seminar was conducted in the Branch to review current projects and to integrate them into the Branch's Research Program on Environmental Improvement. This program represents an intensification of our antipollution efforts and is concerned with minerals-related pollution. A principal aim of the seminar was to collect information in the following principal subject areas:

(a) Total air pollution in Canada from primary and secondary minerals and metals industries (mining, mineral and metals extraction and processing).

(b) Advances in mineral and metal recovery and refining processes and their effect on abating pollutant emission to the atmosphere.

(c) Known properties, both chemical and physical, of pollutants emitted by mineral and metal processes.

(d) Research and pilot-plant facilities of each division and research centre that are now, and may in the future, be useful in the program.

The presentations at the seminar are summarized in the following sub-sections:

2.1. Research on Combustion-Source Pollution at CCRL*

The CCRL research program, which treats studies of combustion-source pollution and flame phenomena as inseparable disciplines, can be roughly divided into the five following topics:

(a) Characterizing pollutants at source.

(b) Minimizing pollutant formation by optimization of flame aerodynamics.

Combustion research program

(c) Reducing pollutants to minimal practical levels before emission by chemical treatment or physical removal.

(d) Dispersing any residual pollutants in the atmosphere by tall stacks to protect air quality, and

(e) Determining the rate at which a selected climatic region or air shed can assimilate pollution.

Flame-research tunnel furnace

Research on the first two topics, being fundamental in nature, will be carried out in a unique, Therminol-cooled tunnel furnace that is divided into calorimeter sections for axial measurement of heat absorption. This furnace is designed to permit continuous probing along the flame axis and will be used to investigate the effect of flame aerodynamics, thermal loading and radiative heat transfer on pollutant formation. Results of this research will form the basis for rationalizing industrial burner designs so that

* CCRL - Canadian Combustion Research Laboratory

emissions of SO_3, NO_x, CO, soot and hydrocarbons can be reduced by efficient combustion. Special combustion probes essential for fundamental flame studies have been acquired from the International Flame Research Foundation in Holland, of which the Combustion Laboratory is a participating member.

Flame probes

Highly sophisticated analytical instruments are available for characterizing pollutants in combustion gases, but proper sample preparation is essential to suppress interferences and systematic errors. For this reason gas sampling and preparation systems have been developed that permit continuous monitoring of CO_2, CO, O_2, NO_x, NO_2 and SO_2 by commercially available instruments. In addition, isokinetic dust samplers have been designed that permit recovery of particulate matter for chemical and physical analyses. We have, on invitation by industry, assembled this dust sampling system as a portable unit to evaluate dust and fume emissions from metallurgical and fuel-fired processes. Analytical methodologies for determining both fixed and free sulphates in combustion residues have also been evolved in collaboration with the Environmental Health Centre of the Department of National Health and Welfare.

Pollution measuring instruments developed at CCRL

Dust sampling

Analysis of Sulphates

Phenomenological studies associated with the fixation, growth and decay of pollutants beyond the flame envelope are carried out in a pilot-scale model of a power utility boiler. This boiler, which may be fired with any industrial fuel, has been used to assess the effectiveness of corrective measures such as low-excess air combustion, low-sulphur fuels, chemical additives and dust removal equipment on reducing pollutant emissions to atmosphere.

Behaviour of Pollutants beyond flame

Experiments with residual oil containing 2.5% sulphur have shown that emissions of SO_3, NO_x and acid-soaked soot can be effectively controlled by the use of low-excess combustion air in combination with a fuel-oil additive developed by the Canadian Combustion Research Laboratory. The additive, which consists of partially dehydrated hydroxides of magnesium and aluminum, also improved the electrical resistivity of carbon soot to the extent that collection by electrostatic precipitators is possible.

Fuel additive developed to eliminate SO_3 and improve soot removal

SO_2 recovery by others

SO_2 recovery processes that are presently under development for use with large thermal generating stations, are being continuously evaluated, but so far all known processes are economically prohibitive. For example, on a 700 MW boiler the Monsanto process for converting SO_2 to H_2SO_4 costs over \$20/kW for capital equipment which corresponds to about 13% of the cost of the steam generator. Credit for the sale of H_2SO_4, assuming a market demand, just balances the operating costs of the recovery process.

CE System

SO_2 removal processes such as the CE limestone injection and water washing system costs \$4/kW for equipment. Operating costs, which are about 0.4 mills/kWh for limestone and labour, will add about 6% to the cost of power generation. A major disadvantage of this system is that dumping grounds must be found for large tonnages of spent dolomite.

Domestic heating pollution, dramatic reduction by blue flame produced in CCRL

Domestic fuel oils contribute to high ambient pollution levels in urban areas, particularly during winter, because residential chimneys emit flue gas at a relatively low level. A potential solution to this problem may lie in the use of blue flame oil burners for home heating. In laboratory experiments with these burners no measurable CO, carbon soot or unburned hydrocarbons were produced with 10% excess air (2% 0_2) and pollutant levels of SO_3 and NO_x were reduced. The conditions necessary for flame stability are now well defined and burner configurations for use in existing oil-fired furnaces and hot-water tanks are being designed.

Incinerator developed to destroy DDT

At the request of the Interdepartmental Committee on Pesticides, the results of this blue flame work have been utilized in fabricating a system for the thermal destruction of DDT. A prototype incinerator has been constructed in the laboratory to establish the design and operating criteria and equipment necessary such that large stocks of DDT can be incinerated without the possibility of land, air or water pollution occurring.

Efficient combustion technology available and applied to Federal heating plants

It is evident that emissions of many pollutants can be minimized by efficient combustion processes. Nonetheless, any residual pollutants that are not removed or neutralized

Plume dispersion

prior to emission must be properly dispersed in the atmosphere by the use of tall stacks. Tall stacks utilize the natural capacity of the atmosphere to dilute as well as convert undesirable pollutants to harmless compounds. It is incorrect to assume that tall stacks transfer pollution from one area to another since increases in stack height cause corresponding decreases in ground-level pollutant concentrations.

Chimney height standard developed

The Combustion Laboratory has drafted a proposed Canadian chimney height standard, based on published plume rise data, for the guidance of industry and pollution control agencies. This standard, which has been published in graphical form, relates heat and pollutant emission rates to chimney height, wind velocity and ground-level pollutant concentration for flat terrain. Factual information on the integrated effects of meteorology, topography and climatology on classical plume behaviour are not yet available; however, the standard is formulated so that dispersion factors for any selected air shed or climatic region may be incorporated at any time.

Air shed dispersion factors being developed or assimilative capacity of atmosphere

To determine dispersion factors for the main climatic regions in Canada, aerial probing of hot plumes was initiated in August 1969 with the active collaboration of the Ontario Department of Energy and Resources Management, Ontario Hydro and the Meteorological Branch of the Department of Transport. Results of this first study revealed that plume trajectories and boundaries can be accurately defined and that meaningful dispersion factors can be derived from measured data.

Incineration studies

Another area receiving close attention is pollution from the incineration of municipal refuse and industrial wastes. A literature survey and field studies of present incinerator practices around the world are well underway and the fabrication of an afterburner to incinerate coke oven effluent is nearing completion.

Auto and aircraft pollution research by others

Pollution from motor vehicles and aircraft has become an area of prime concern in urbanized areas which have a high density of highways and roads and are in the vicinity of airports. Data have been collected that show the proportion of the total man-made pollutants for which the motor vehicle is responsible, and also how different types of engine and

New engine development in Holland

engine power influence the production of pollutants. The introduction of emission control devices has resulted in a considerable reduction in the emission of pollutants from the gasoline engine. Despite some skepticism the Stirling engine shows promise having almost pollution-free operation. Development work in Holland indicates that this engine could replace the conventional diesel engine in a few years and perhaps be adapted to power passenger cars.

Data on the rate of emission of major pollutants from various types of aircraft clearly indicate that the major problem is during taxiing when the plane is still on the ground.

Noise pollution

Finally, it must be emphasized that air pollution abatement measures must not result in other forms of environmental pollution. A typical example is noise pollution generated by flames and equipment associated with pulsating and sonic flames. The laboratory is equiped to analyze noise spectra and is well versed in the application of noise suppression techniques.

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2.2. Fuels Research Centre (FRC)

2.2.1. Introduction

Air and water pollution inseparable

Though this seminar is to be devoted to atmospheric pollution, it seems appropriate to mention at the outset that the Fuels Research Centre is concerned with various special aspects of the contamination of our environment. These consist of pollution arising from combustion sources as well as those connected with the production and processing of coal and petroleum. Sometimes the pollutants affect the air, and sometimes it is the rivers and lakes that are principally concerned.

The contamination of the water by petroleum frequently arises as the result of spillage but occasionally natural seepages are responsible. In this situation considerable

FRC identification of oil in water

analytical work is required to determine whether the oil is of natural origin, but possibly weathered, or whether it is a refined product which may have been altered by migration and weathering. Should the contamination be due to a natural seepage, it is usually important to examine those properties that are of the greatest geochemical significance.

Harmful pollution man-made

It is appropriate at this point to make some general comments on the nature of the pollution problem. Within the earth's environment, life has evolved during a period of a billion or more years, and the number of living things has multiplied so rapidly that it seems as though life itself is destined to despoil or render unusable the very biological chain that has made life possible. Human beings are the one form of life that is making the greatest inroads on the environment. To ask human beings to completely stop altering the environment or using it would be asking them to cease living. Human beings evolved because of the earth's environment, they live off the environment, and in living they inevitably change it. The problem is then how to avoid despoiling and degrading the environment so that human life is worth living for the swelling multitudes. Finally man must curb his numbers and guide his technology if human life is to be even possible.

Population control

2.2.2. Pollution in Various Regions of The Atmosphere

First of all we may begin by considering the four types of air pollution with which we are concerned at the Fuels Research Centre, these are:

FRC areas of concern

(a) Mine air.
(b) Pollution arising over a typical urban centre (that is up to the inversion layer)
(c) Pollution at the inversion layer.
(d) Upper atmosphere.

2. 2. 3. Mine Air

Mine air analysis since 1915

In the field of mine air analysis the Fuels Research Centre has since its founding in 1915 acted as a referee laboratory for the analysis of mine atmospheres. This service was initiated to limit the hazards which could affect the safety of mining operations in Canada, and consists of determining the composition of mine atmospheres and diesel exhaust samples to ensure proper mine ventilation, and that the toxic and combustible gas content is within statutory limits established by the various provincial and federal authorities involved. Specifically this amounts to determining the concentration of combustible gases (methane, ethane, propane ....) present as well as that of the toxic combustion products CO, NO_x and aldehydes arising from the use of diesel engines and explosives. The mining inspectorates of the various provinces require mining companies to send gas samples to the Fuels Research Centre for analysis to calibrate the control instruments. The Fuels Research Centre also attempts to give the best possible advice to the inspectorates on the selection of instruments for the analyses of gases in mines, and to issue gases with a certificate of analysis to enable mines to standardize their instruments.

Dust, Diesel, Exhaust, Methane, Ethane, Propane, CO, NO_x, Others

In the matter of instrumentation for monitoring atmospheric pollution, it would be well if the Fuels Research Centre followed in some detail the efforts of the State of New Jersey which currently is spending 2. 3 million dollars annually on air pollution, as part of the activities of the Division of Clean Air and Water of the State Health Department. This state has six mobile monitoring stations monitoring continuously nitrogen oxides, nitric oxide, sulphur dioxide, oxidants, aldehydes, carbon monoxide hydrocarbons, particulates as smoke shade, and carbon dioxide. The performance of this equipment in relation to that which we are currently using should be reviewed in order to make the best possible selection in relation to the diesel testing program.

New Jersey mobile monitoring stations

2.2.4. Atmospheric Pollution in Major Centres of Population

U.S. pollution by auto, manufacturing power generation, incineration, combustion.

President Nixon recently stated that the automobile is the worst polluter of the air. This statement may have been based upon the recent study of the National Academy of Sciences in the U.S. entitiled "Waste Management Control" in which it estimates that 59.9% of the air pollution comes from transportation, 18.7% from manufacturing, 12.5 % from electric power generation, 6.3% from space heating, and 2.6% from refuse disposal. Carbon monoxide, chiefly from combustion sources is the chief pollutant consisting of 52% of the total, oxides of sulphur come second with 18%. Other important contaminants are hydrocarbons 12%, particulate matter 10% oxides of nitrogen 6% and other gases and vapours 2%.

Effects of SO_2

Sulphur dioxide is one of the more irritating gases to humans, and toxic to green plants. The levels of concentration of this substance in air that are toxic from a human point of view are a subject of considerable uncertainty. Recent studies have shown that low concentrations tend to increase the life of mice. While SO_2 emissions in New York City during the past four years have been reduced by 50% according to Merrill Eisenbud, within the same period the content of oxidants ozone, nitrogen oxides and nitrates and nitric acid coming from automobile exhaust has risen. Mr. Austin N. Heller, New York City's Air Resources Commissioner wonders if SO_2 in the air does not contribute to blocking certain photo-chemical reactions which produce the most objectionable pollutants. This merely proves that much remains to be learned about air pollution before meaningful regulations can be adopted.

SO_2 reduction and auto exhaust increase in N.Y. City

Photo-chemical reactions

Pyrolysis products carcinogenic found in U.S. Cities

Of the organic pollutants, the pyrolysis products of coal, petroleum, and organic matter are considered to be much more toxic than the natural hydrocarbons. In particular benzo(a)pyrene is considered to be one of the most active carcinogens in animals and may be carcinogenic in humans. This compound has been found in the air of most American cities as shown in a paper by T. W. Stanley.

Leaded gasoline not now health problem

Returning to the automobile exhaust problem, there does not seem to be any evidence as yet that lead tetraethyl burned in gasoline gives rise to any serious public health problem in spite of the fact that 237,589 metric tons of lead in this form were burned in 1968 in the United States. Nevertheless, lead residues are found in the snow in even the most remote areas of the world such as the Antarctic continent. It is generally recognized that this accumulation cannot go on indefinitely. Oil companies would prefer to eliminate lead tetraethyl because of its potential hazard to health and due to the fact that it contaminates the catalysts used to remove other pollutants from automobile exhaust.

Oil industry taking preventive action

Lead-free high octane gas is expensive

The technology for the production of lead free gasoline with high octane rating (100 octane) is known but it is expensive. The alternative is to build low compression ratio engines that are less efficient and use cheaper fuel.

Mr. John O. Logan, President of Universal Oil Products, states that the capital requirements are not linear. For example, a typical 90,000-barrel per day refinery would need a capital investment of less than $1 million to reduce the lead level to 2 ml from a base of 2.5 ml. But costs would soar to more than $7 million for a 1 ml level and $14 million for complete removal. Nationwide total elimination would take about $2 billion in added capital investment. The problem of capital supply represents a serious deterrent to a change in refinery practice.

IIEC developing catalytic exhaust after burner

At the present time the Ford-managed Inter-Industry Emission Control (IIEC) group is working on catalytic devices to meet increasingly restrictive emission standards. This group was formed in 1967 by Ford and Mobil Oil later joined by other auto-makers and oil refiners. IIEC is working on catalytic after burners for oxidizing hydrocarbons and devices to reduce the oxides of nitrogen.

California regulations

California has taken the lead in stimulating the development of mechanisms to reduce emission of pollutants from automobiles. It is stated that cars now produced and sold in California must not emit more than

180 ppm (parts per million) unburned hydrocarbons compared with the 900 ppm emitted by the cars produced before 1966. The U. S. Federal Government is considering adopting these as national standards in 1970. In the meantime California has provided that after 1972 the hydrocarbon emissions shall be reduced to 120 ppm.

It is already clear, however, that these standards do not go nearly far enough. The number of automobiles is increasing, and the number of miles driven per car per day is increasing. Hence, the total tonnage of pollutants emitted to the air by automobiles will start to increase again by 1980. Wholly new technologies are now being sought to take care of this situation.

As an interim measure catalytic after-burners are being designed and built. At the present time the objectives of automobile after-burner design are to reduce the emission concentrations to 1.5% CO and 180 ppm of hydrocarbons which assumes an average exhaust composition of 4% CO and 900 ppm of hydrocarbons. This is to say that the catalytic after-burners should have a conversion of 80% when new and 60% after 12,000 miles or 300 hours of operation. This performance should be capable of being obtained under conditions of a cold start and frequent periods of breaking.

Catalytic after burner objectives

The work on catalytic after-burners at the Institute du Pétrole has shown that cobalt oxide on alumina cannot be employed on a support of alumina or silica as it reacts with the support to give cobalt aluminate which is inactive. The stabilization of the alumina support with calcium is not sufficiently effective. The use of thorium and zirconium as stabilizers is too expensive. The use of silver as catalytic agent is excluded because of its high price and because it reacts with traces of chlorides to produce fusible and inactive silver chloride. The most promising catalyst at present appears to be a copper oxide supported on alumina. This catalyst is not effective unless the x-ray diffraction lines of CuO are apparent. The maximum concentration is limited by a reduction in porosity and slow thermal reaction with alumina.

French catalytic after burner research reveals serious limitations

FRC catalysts

The Fuels Research Centre has developed alumina supports for catalysts with high surface area and good mechanical strength, it remains to be seen whether these supports will find an effective role in the after-burner application.

Improve combustion for power generation

Fuel additive

Chimney height standard

Turning to the problems of pollution arising from thermal power generation, the approach adopted by the Fuels Research Centre has been to investigate methods of improving the combustion with a view to lowering the production of CO, and converting as much SO_2 to SO_3 as possible, as this compound can be more readily removed by fuel oil additives. While this approach is possible with oil, it is not possible in large coal-fired thermal power stations. The approach has been to provide better information on which to base the design of the height of smoke stacks to disperse the pollution. Although it is recognized that dilution of pollutants mitigates some of the acute aspects of pollution by transferring them up to the inversion layer, this solution has limits. For example, at LaPorte, which is south east of Chicago, the rainfall is 47.1" or 19" more than at the weather stations up wind of Chicago. LaPorte's rain pattern follows the number of days of haze and smoke in Chicago and the peaks in steel production.

Pollution and influence on weather

2.2.5. Pollution in the Upper Atmosphere

The difficulties associated with pollution are not entirely confined to the inversion layer and below.

Dust in upper atmosphere lowers world temperature - causes cloud formation

The repeated flights of jet aircraft between New York and Chicago have caused a cirrus cloud bank to form which persists 90% of the time. Professor R. A. Bryson of the University of Wisconsin claims that the same situation is developing between New York and London, England, where cirrus cloud cover has increased by 10%. Professor Bryson claims that there is little agreement that the greater dustiness of the upper atmosphere is contributing to another phenomena, a world-wide cooling trend. There is little argument that since 1940 the world as a whole has fallen in temperature by 1/3 to

4 to 5°F temp. drop caused last ice age

1/2 a degree, which does not seem like much until you consider that the last ice age was brought about by a temperature drop of only four or five degrees. The dirt and high level cirrus clouds have increased to the point where they are reflecting away enough sunlight to over-ride the other factors tending to raise the temperature of the earth surface as the growing CO_2 concentration. At this point there does not appear to be a solution to this problem from the fuel point of view.

Hydrogenate crude for better fuels

To return to the fundamental problem of producing hydrocarbon fuels of high purity, there appears to be no economic alternative other than the hydrogenation of crude oils. We visualize this refining step as playing an ever growing part in the techniques to fight pollution.

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2.2.6. Explosive Atmospheres Research

Continuing research was discussed in connection with safety in mines where explosive atmospheres occur. While this goes a long way back, for example to the invention of the Davy lamp, new problems are continually arising, due partly to introduction of new mining methods and new materials into mines. In the event of mine fires, some substances which have been used for sealants such as polyurethane produce phosgene and hydrogen cyanide. Because 9 deaths of miners in Scotland were attributed to this cause it has been banned from U. K. mines. In the certification investigations of the Canadian Explosive Atmospheres Laboratory it is therefore important not to certify conveyor belting, plastic ventilating duct, sheeting, etc., without considering the possibility of introducing an unexpected hazard.

New mining methods and materials used may increase hazards

Gas alarms studied

Laboratory investigations have been conducted on safety and reliability of performance of a number of flammable gas alarms or monitors. Considerable work has been done in countries such as the U. K., the U. S.,

Germany and Japan on instrumentation for monitoring mine atmospheres.

Diesel exhaust studies for many years

The subject of pollution of mine air and/or tunnels by diesel engines has been studied in great detail, albeit intermittently, over a period of seventeen years by personnel of the laboratory. Several investigations of diesel powered apparatus have been conducted and close contacts have been maintained with the U. S. Bureau of Mines who are very experienced in this field. Mr. Brown said that a facility for conducting tests of diesel engines up to 400 HP at various engine loads and speed had been designed. The space was provided in the new building of the Canadian Explosive Atmospheres Laboratory. The dynamometer has been ordered. It is expected that the instrumentation for analyzing the exhaust gases will be purchased in 1970 and the laboratory may be operational in about two years. It will be possible to use the facilities to conduct tests of gasoline engines or effectiveness of such devices as catalytic exhaust purifiers.

New diesel engine test bed at Certification Laboratory

2.2.7. Research on Oil Refining

2.2.7.1. Introduction

Petroleum refineries have in the past, and with some justification, been designated as major contributors to the pollution of our natural environment.

Refinery location

Prior to World War II, refineries were built close to oil fields and the products shipped from these low population areas to densely populated regions of industrial nations. Today refineries are normally built at the centres of the markets they serve. Even the concept of the seaboard refinery is no longer valid as pipelines can deliver crude safely and economically from ocean terminals to the centres of continents.

As refineries were moving toward the centres of population, the general expansion of industry was developing a gradual public awareness of the potential dangers created by industrial pollution. Newcomers such as refineries usually already conspicuous by their size were viewed with more than normal suspicion.

The oil industry, conscious of this poor image, became increasingly aware of the need to live as a responsible neighbour and the value of good relations with the public.

Refinery pollution by spillage

Being a mobile fluid, oil spillages are less easy to contain than solids and its refining, unless carefully controlled, can be offensive. In addition the products from refineries as fuels on combustion can pollute the atmosphere just as do solid fuels. Hence the oil industry has recognized that it has a twofold duty and has taken and continues to take, preventive and remedial action. During the last three years the U.S. oil industry has spent close to 500 million dollars in air environmental control.

Abatement facilities costly

In general, the investment and operating costs of air pollution abatement facilities in the oil industry are far from profitable with the exception of carbon

CO waste-heat boilers

monoxide waste heat boilers, sometimes built in conjunction with catalytic cracking units, where good pay outs can be realized.

Facilities installed to abate air pollution emanating from oil industry facilities (refineries, terminals, etc.) should be distinguished from facilities installed to reduce the pollution potential of the oil industry's products (gasoline, natural gas, distillate and residual fuels, etc.) most of which end up as combustion products in the atmosphere. In the U.S.A., to 1968, the capital investment made in the first category was roughly 250 million dollars, and in the second category for product desulphurizing alone, an investment of 685 million dollars with an operating annual cost of 165 million. Figures for Canada are not available, but they are without doubt at least on the same scale.

U.S. spending many millions

Canada spending on same scale

Sometimes, attempts are made to predict the amounts of pollutants emitted into the atmosphere based on the potential of pollutants in the total fuel consumed in a country or region. However, this method must be used with caution as obviously it is strictly limited to areas with roughly comparable distribution of the sources. Otherwise, well controlled emissions in sparsely populated areas, which do not exceed the standards set for ground level concentrations, or emissions from sufficiently tall stacks, which contribute very little, if at all, to pollution in city areas, would be included with undue weight.

Prediction of pollution emission criticized

2.2.7.2. Air Pollutants From Oil Refineries

1) Sulphur Dioxide

SO_2 is the most widely publicized potential atmospheric pollutant from oil refineries. Although much has been learned and written about the nature of the pollutant both by itself and in combination with particulates, the effects of SO_2 on public health, vegetation and materials are still largely unknown and opinions of the experts vary considerably.

Three major approaches are available for control of SO_2. The first is to use fuels produced from naturally occurring low sulphur crude oils. The second is to remove the sulphur from the fuel before combustion. Most large modern refineries employ catalytic desulphurizer units to remove sulphur from naphtha, distillate and cracking feed stocks. This is a replacement for the old liquid caustic washing processes. Sulphur compounds are converted to hydrogen sulphide which is then stripped and converted to elemental sulphur.

Refinery SO_2 recovery international

Desulphurizing of residues and heavy fuel oils presents difficulties, however, and is not yet practised on any extensive scale. It is possible to desulphurize heavy gas oils and then blend them back into the residue to reduce the overall sulphur content of the fuel oil. However, sulphur dioxide deriving from their combustion is mainly dispersed from high stacks. Other sources of sulphur compounds are from fluid cokers, cat cracker regenerators and incinerator tail gas from the end of the sulphur plant. All these go up the main stack of the refinery as SO_2 emissions to the atmosphere. The third method of SO_2 control is the removal of sulphur compounds from the stack gases. Various methods of desulphurizing flue gases have been tried. The simplest is the wet washing of the gas to remove the SO_2. This has been practised at Battersea and Bankside power stations in London, England, and is far from an ideal process. The wet and cold plume produced has little buoyancy and under some weather conditions can actually cause a type of "rain" in the neighbourhood. Several other processes appear to have some potential for economic development, although their application would probably be limited to large plants. These include:

Flue gas SO_2 recovery by others

(a) Dry Dolomite Injection with Wet Scrubbing Process;
(b) Catalytic Oxidation Process;
(c) Alkalized Alumina Process; and
(d) Reinluft Dry Char Absorption Process.

The economics of these processes are sensitive to the market price of the by-product sulphur or sulphuric

acid product. As yet there has been no sign by industry of pressing this solution to the sulphur dioxide problem as an alternative to the high stack.

2) Hydrogen Sulphide and Mercaptans

Objectionable odours

Malodours are probably the most likely of all pollutants to cause public resentment whether or not the source of the malodour is dangerous or not. This is true because they are so obvious that the public's attention is immediately attracted.

Hydrogen sulphide and mercaptans are two such pollutants. They are emitted from oil refineries only in very low concentrations, generally from refineries using the more old-fashioned sweetening processes where some escape of these vapours is hardly avoidable. In the modern catalytic desulphurization processes, sulphur compounds are converted to hydrogen sulphide which is then stripped and converted to elemental sulphur.

Hydrogen sulphide and mercaptans are found dissolved in the "spent soda" of the old-fashioned sweetening processes and in the sour condensates from atmospheric and vacuum distillation plants and from catalytic processes. The first of these has been largely eliminated by hydrodesulphurization, but the sour condensate problem remains. These, if they are simply discharged as effluent, cause an offensive odour and result in a waste of potentially usable condensate. One remedy is to strip the condensates with steam or flue gas or both and burn the off gas, but this results in an increase in SO_2 emission. Phenolic condensates and spent soda are particularly malodorous. The condensate is sometimes used in crude oil desalting wash water and, if the refinery uses once through cooling, the sour effluents are effectively diluted. The only wholly effective method of destroying these odours is biological oxidation of the effluent.

3) Oxides of Nitrogen

NO_x not refinery problem

Oxides of nitrogen are not at present considered problems in oil refineries, but they become so when fertilizer plants making nitric acid are built in association with refineries.

Reported values for concentrations of nitrogen oxides from industrial furnaces and boilers range from 200 to 1000 ppm. An increase in flame temperature of the particular process favours nitrogen oxide formation. At present, information on the formation of nitrogen oxide and its concentration in the atmosphere is limited. The main adverse effect of oxides of nitrogen is their influence in the formation of photo-chemical smog. However, from widespread research, it has been determined that photo-chemical smog is a rarity depending on a combination of climate, topography and hydrocarbon and nitrogen oxide emissions (predominantly from automobiles). It is unlikely that photo-chemical smogs will become a problem north of about the 40° latitude (and hence in Canada) or where cars are fewer than found in the very largest cities of the U. S. A.

4) Hydrocarbon Vapours

Refinery H_xC_y leakage

Hydrocarbon vapour emission is in many cases the result of leakage from storage or process equipment. The use of floating-roof tanks largely eliminates leakage when filling crude oil or light distillate storage tanks. Blanketing with dry inert gas is also practised and recommended. Leakage from pump glands, seals, etc., is a matter of housekeeping. Odours from biological oxidation units are sometimes objectionable. A particularly objectionable hydrocarbon emission is that from the air blowing of asphalt and bitumen. The resultant heavy yellowish fumes are a totally unacceptable discharge. Simple burning in a process plant furnace is not particularly effective. It must be destroyed at high temperatures in a special chequer brick furnace with high excess air.

5) Smoke

Refinery flares

Furnaces burning gas or fuel oil do not normally smoke if properly regulated. Smoke emission from refineries is associated mainly with flaring of excess gas and most refineries do not normally operate with a continuous surplus of gas. However, during upsets or for refineries that do operate with a surplus, considerable quantities of gas must be flared.

Smokeless types

There are two types of so-called "smokeless" flares both with disadvantages. The first operates on the gas-mantle principle using carborundum or alumina rods within a brickwork shield. The rods become white hot and the carbon in the flames is fully oxidized. This type of flare, however, only remains smokeless when the quantity of excess gas to be burned remains constant.

The second "smokeless" flare utilizes steam injection and while effective it requires a large amount of steam and a fairly constant supply and quality of gas. The steam injector flare also tends to be noisy and presents a glare problem. Flares, of course, should be elevated where possible.

6) Particulates (other than smoke)

Solid particles may be fuel ash with unburned carbon dust and catalyst fines from fluid catalytic crackers, or "acid smuts" from acid tar burning. These latter are paricularly offensive as they can be carried long distances and due to their acid content can do considerable damage to fabrics and other materials.

Acid soot problem

Some larger plants employ acid recovery units. Others get rid of their acid tar to chemical manufacturers. However, some refineries must still burn it and, unless proper combustion practice and equipment is employed, acid smuts are the result. A special high-temperature brick furn ace is used similar to that used for disposal of fumes from asphalt blowing.

Sarnia Chemical Valley Pollution monitoring program

Sarnia's petroleum refining and petrochemical industry (12 companies) have formed what they call the Lambton Industrial Society and together with the Ontario Research Foundation have set up an air pollution monitoring program in Chemical Valley. They report that the area is controlling adequately the emission of SO_2, H_2S and oxidants, but they are still high in dust fall -- suspended particulates and aerosols.

7) Fluorine

HF rigid control

Fluorine compounds emission can occur from the HF alkylation process. The cost of fluorine and its danger to personnel, however, has resulted in stringent safety precautions being taken to prevent its emission.

8) Noise

Noise no problem

The oil refinery is normally a small offender with regard to noise as an environmental pollutant (that is compared to common urban emissions). However, the use of flares on refineries is coming under closer scrutiny and increasing criticism not only because of smoke but also because of noise and glare. There is room here for more work on improving the design of flaring equipment.

9) Hydrogen Chloride

HCl toxic

The chlorine content of fuel oils is small and emissions from refineries amount to only about 1/300 that of SO_2. However, HCl emissions probably contribute considerably to material damage. Whereas sulphates formed from sulphur oxide on calcareous or metallic surfaces tend to produce a protective layer, chlorides have a high water solubility and are readily and continuously removed exposing fresh surfaces for further attack. In addition, medical authorities indicate that as a health hazard, minimum acceptable values for HCl are much lower than for SO_2.

10) Carbon Monoxide

While automobiles must take the blame for the bulk of CO emissions, industry also introduces this pollutant into the atmosphere. The carbon monoxide content of flue gases, for oil burning equipment operating normally, runs between 35 - 60 ppm and in refinery practice is normally dispersed from elevated stacks.

2. 2. 7. 3. Water Pollution From Oil Refineries

Most refineries are situated on waterways having a limited self-purification capacity requiring strict control of waste treatment.

The major amount of oil waste is present in the process water which is defined as any water which has been in direct contact with oil, either liquid or vapour, such as condensates, water used for washing oil products, cooling water from pump glands, water used for cleaning purposes, water drained from supply tanks and rainwater from the immediate vicinity of processing units.

Oil products in water

In addition to oil, process water from thermal and catalytic cracking units may also contain relatively small amounts of soluble compounds, principally sulphides and phenolics, but also some cyanides and nitrogen compounds. Further, spent caustic, spent acids and sludges may cause a disposal problem.

Efficiency of processing has helped decrease pollutant emission by reducing the amounts of losses and waste products. The development of new reagents and processes for removing undesirable compounds from distillates has also contributed. Hydrodesulphurization for example, removes the sulphur as hydrogen sulphide which is then converted to sulphur by partial oxidation.

Close attention to the possibilities of re-using water and the development of air-cooling have also

In-plant recirculation of water

contributed by lowering the water consumption to crude oil ratio from 35:1 in older refineries to as low as 0.5:1 in some modern refineries.

1) Sulphides, Mercaptans, Ammonia

In a modern refinery, process water containing sulphides and other objectionable volatile material, is stripped in a tower. For removal of H_2S and the lower mercaptans, a temperature of 85 to 140°F is sufficient, using flue gases or fuel gas and steam and employing pH control. NH_3 removal requires a temperature of 230°F and pH between 8 and 9. The off-gases are burned or sent to a sulphur recovery unit.

Sulphides and mercaptans can also be removed by oxidation with air mainly to thiosulphate. This process can also be used for spent caustic solutions containing sulphides.

2) Oil

Oil removal from water difficult

Special gravity oil separators are employed. The generally accepted criteria for design of the commonly-used API separators are contained in the "Manual on Disposal of Refinery Wastes" of the American Petroleum Institute. The Royal Dutch Shell Group have improved efficiencies with the "Shell Parallel Plate Interceptor". However, total removal of oil from waste water can never be achieved with gravity separators alone. The smallest oil droplets will remain in the water and very fine suspended solids, to which oil is adsorbed, will approach the density of water and pass through the oil separators.

Some refineries pump this effluent directly to nearby water streams. However, if restrictions do not permit this, then further purification is required not only with respect to the oil, but also other dissolved organic material such as sulphides and phenolic compounds. Chemical flocculation can be applied with the aid of ferric or aluminum salts. Air flotation can also be used. In this process, air is dissolved in

the effluent at a pressure of 2 -4 atmospheres. Just before or inside the separator this pressure is released with the result that a great many air bubbles are formed which entrain oil droplets and suspended solids on their way to the surface where the oil-foam is skimmed off.

3) Other Contaminants

If it is also necessary to remove dissolved oxygen-consuming contaminants, and those affecting the appearance and taste of the water, then further purification is applied. Phenolic compounds and traces of other hydrocarbon derivatives are chief offenders. To remove these organic compounds, bio-oxidation processes are used, based on intensifying the natural self-purification process of water by means of making the living circumstances for oxidizing bacteria as favourable as possible. Part of the organic material is oxidized to CO_2 and H_2O with the aid of oxygen dissolved in the water for energy supply. Three main processes are applied.

Bio-oxidation

(a) Bio-oxidation ponds -- In oxidation ponds without artificial aeration the oxidation utilizes oxygen from the atmosphere plus oxygen produced from photosynthesis.

(b) Activated sludge units -- Basically an aeration tank containing active micro-organisms and the activated sludge . Air is introduced by means of rotating brushes or turbines on the surface or distributed through perforated pipes.

(c) Trickle filters -- Active micro-organisms are concentrated as a layer of "slime" on the surface of a pile of stones or coke in an open concrete tank with a perforated bottom. The water to be purified is poured onto the stone mass by means of rotating distributor arms, the water drips from stone to stone, the organic matter being adsorbed into the slimey mass and used again partly for cell growth, partly for energy supply by

oxidation. Air flows through the tank from the bottom upwards.

4) Sludge Disposal

A difficult problem in dealing with refinery wastes is the handling and disposal of sludges. The solid content is usually between 1 and 2 per cent. By settling in tanks with slight mechanical stirring the solid content will increase to between 5 and 9 per cent. Further thickening is generally done by centrifuges or by filtration using filter aids and steam. Solid contents in this way can be increased to as much as 45 per cent. The thickened sludge is then incinerated.

2.2.8. Contribution to Pollution Abatement by Fuels Research Centre

Low-sulphur oil projection

More than 50 per cent of the Free World total energy demand is in the heavy fuels market where residual fuel oil competes with natural gas, hydropower, coal and nuclear energy. By 1975 it is forecast that over 60 per cent of the on-shore residual fuel oil market will require a low sulphur product.

U.S. sulphur limits

The trend of legislation in most countries is to progressively limit the sulphur content of all fuels. Most cities in the U.S.A. are already banning the use of fuels containing more than 1 per cent sulphur (in New York City - 0.37 per cent by October, 1971).

Must desulphur in future

These increasing restrictions cannot be met indefinitely by selecting crude oils from low sulphur sources. Ultimately, the problem of desulphurization of residue and heavy sour crude and bitumens with sulphur contents between 3 and 6 per cent and of which Canada has an abundance, must be faced along with increased costs and new and improved techniques and catalysts.

Expressed in a very few words, the objective of the research program of the Petroleum Group at the Fuels Research Centre is the development of improved

FRC plans new refining techniques

techniques for refining the low-grade oil reserves to meet the demands of both air pollution regulations and Government Conservation Boards. While the high quality crude oils are presently being used for the production of all grades and types of fuels, they are best suited to the production of gasoline and the lighter hydrocarbon fractions. The lower grade oils are potentially suited to the production of the heavier fuels, diesel and domestic heating oils. The problems will undoubtedly become greater in the future as consumption and demand increases and air pollution regulations become more restrictive. It is generally felt that the development of practical and economical means to reduce impurities must be devised quickly to permit the orderly use of the whole hydrocarbon resource.

High-press. hydrogenation

The main research effort of the Petroleum Group has been on the development of techniques for the removal of sulphur from the low-grade fuels before combustion. The amounts of sulphur involved are large (and valuable) and the reasoning has been that it should be easier to remove contaminants from a comparatively small volume of liquid fuel than from a large volume of combustion gases. It has been demonstrated in our own Mines Branch Laboratories, as well as in American and European research centres, that low-grade liquid fuels can be purified by high pressure catalytic hydrogenation. For example, more than 90 per cent of the sulphur present in bitumen extracted from the Alberta Tar Sands can be achieved by hydrogenation over cobalt molybdate catalyst at 3000 - 4000 psi. Extensive cost recovery is attained through sales of sulphur and improvements in hydrocarbon quality. The principles involved in catalytic hydrogenation are well known, but the engineering processing techniques have been slow to evolve largely as the result of the reluctance of the petroleum industry to accept the necessity for high hydrogen pressures. As air pollution control increases (and the resource value of huge deposits of low-grade oil decrease as the consequence) the alternatives become more palatable.

Industry cautions of high H_2 press.

Hydrogenation limits

High pressure hydrogenation is by no means the cure-all for the problem of contaminants in fuels. It permits considerable improvement but, in some respects, it creates as many problems as it solves. A great market demand is for inexpensive (sulphur free) residual oils in the class of Nos. 5 and 6 fuel oil. Unfortunately, the products of hydrogenation processes are largely high quality distillate fuels which are in a quite different category, and price range, from residual fuel oil. The techniques have yet to be devised for desulphurizing residual fuels without up-grading the hydrocarbon quality. It may be that it is not possible to accomplish desulphurization without up-grading .... the chemistry of the sulphur linkages in many types of heavy oil suggests that some cracking of the hydrocarbon structure must accompany sulphur removal. The problem is one of degree. Preliminary trials in our laboratories indicate a measure of success by hydrogen-treating for long periods at low temperatures. Such an approach is a marked departure from conventional refinery practice where the ultimate goal is as much through as possible in the shortest time. There are a great many areas to explore, time, pressure, temperature and, of course, catalyst. The possibilities for improvement in the last are endless.

FRC promising technique

2. 3. Research on Mine Atmosphere

Mine air sampling and analysis

The Mines Branch is concerned with mine atmospheres in two ways. First, staff and facilities are engaged in research on methods of measuring such aspects of air quality as dust, gas and radioactivity concentrations. Second, engineering studies are undertaken on the feasibility of integrating research findings into practice and up-to-date knowledge is maintained on current advances in mining practice.

Heat pollution

Humidity

Wind chill

Light

Noise

Gas

Radiation

With regard to mine atmospheres (which is somewhat broader than the subject of air quality), interest and some knowledge is available on the following topics: heat, which can be critical in deep mining (and, depending on the geothermal gradient, in not-so-deep mining), is a factor that requires the expenditure of funds to maintain human working conditions in many areas, e. g. at a depth of 9, 000 feet the rock temperature at Timmins is 85° F, at Kirkland Lake is 102° F, Sudbury is 122° F, at Bralorne is 185° F and on the Rand in South Africa is 105° F; humidity becomes particularly important at high temperatures as the human body can only be cooled by evaporation, which requires less than 100% relative humidity; wind chill is similarly important as moving air is equivalent to a lowering of temperature; light is considered an important aspect of the mine atmosphere with respect to both working efficiency and physiological effects; noise is another important aspect of the mine environment and increasingly is considered to be similar to air pollutants; gas such as methane, radon and internal combustion engine fumes can be critical factors both with respect to operating economics and physiological effects; and radiation which can be important in other mine atmospheres besides those of the uranium mines.

2. 3. 1. Respirable Dust Hazard in Mines

Dust hazard

Mining processes create artifically high concentrations of dust and associated pollutants which can lead to severe lung diseases in miners. The magnitude and severity of the problem can be appreciated

by considering the many dust and disease relationships which have been identified and a few of the statistics put forward in the last decade by countries where mining is a major primary industry.

Dust and lung disease

Some examples of the dust and disease relationships are:

Type of Dust	Form of Lung Cancer
quartz, quartz rich minerals	silicosis
crocidolite asbestosis	mesothelioma
chrysotile asbestos	asbestosis
coal	black lung
tin oxide	stannosis
radon and radon daughters	lung cancer

U.K. compensation to miners

In Great Britain, 48,563 miners were receiving benefits for lung diseases in 1965; of this total, 47,264 were from the coal industry. In the same country in 1966 the total annual cost in pensions and benefits to miners was about £13,500,000 and an additional £5,000,000 were spent for preventive measures and research. In other words for the year 1966, Great Britain spent £18,500,000 or 2/s per ton of coal mined on miner's lung disease problem.

In West Germany the total cost of silicosis was estimated as £45,000,000 or 8-9/s per ton of coal mined.

In South Africa a total annual sum of £5,000,000 is spent on miners lung disease problems.

Canada follows pattern

In Canada national statistics are not available. However, because of the diversity of the industry and the complexity of the deposits, it is reasonable to expect comparable statistics. In Ontario, gold mines presently pay a $4 per $100 payroll assessment. However, many segments of the industry are dust-conscious and in co-operation with research laboratories and other organizations have had measurable success in methods to control mine environments.

To control respirable dust in mines, the general practice is to lay down a maximum allowable concentration (MAC) or threshold limit value (TLV). This limit is based on the best available evidence - medical, scientific, industrial - and is a provisional arbitrary standard. The objective of course is to set standards to represent conditions to which the workers may be repeatedly exposed day after day without adverse affects. Some USA standards are as follows:

U.S. mine air quality standards

	Particles per Cubic Centimeter pp cm3	Million particles per cubic foot mp ft3
Asbestos	176	5
Inert dust	1765	50
Quartz - 20%	353	10
50%	158	4.5

In addition to the dust control measures in mines, periodic clinical check-ups and medical examinations of the miners detect early stages of pneumociniosis development and allow withdrawal from the mines of the affected miners.

2.3.2. Environmental Control Group, Mining Research Centre (MRC)

The Mines Branch in keeping with its policy to assist and to provide knowledge and understanding where scientific gaps exist looked into the problems associated with airborne dust in mines. Subsequently, in light of the growing seriousness of these environmental problems with the advent of mechanization and deep-mining the

Environmental Control Group was established within the Mining Research Centre to carry out research in selected areas where information was required.

Facilities for environmental control studies are housed in the Elliot Lake Laboratory of the Mining Research Centre. Here 1,500 square feet of floor area accommodates a dust physics laboratory and a radiochemistry laboratory.

Environmental control group at MRC

The dust physics laboratory is equipped to simulate dusty environments artifically and to assess the properties of these and natural occurring dust clouds. Stable dust clouds with controllable size distribution and concentration are generated in an open circuit, walk-in, dust chamber designed with

Dust studies

sample ports for remote operation of measuring instruments. For evaluation purposes, the specialized pieces of equipment required such as microscopes, microprojector, balance and particle size analyzers are available and in addition, limited chemical capabilities for compositional analysis. For identification of small quantities of multi-component mineral dusts,

Analytical facilities

X-ray diffraction and infra-red spectroscopy are being considered. For the present, equipment at the Mines Branch Ottawa is being used, but it is hoped to establish the X-ray equipment at Elliot Lake in early 1970.

The radiochemistry laboratory has a multichannel pulse height analyzer for the qualitative

Alpha-gamma measurement

identification and quantitative measurement of alpha- and gamma-emitting radioisotopes, as well as the usual chemical laboratory equipment for studying the non-radioactive properties of materials under investigation. Proposals have been submitted to install an ultra-violet visible spectrophotometer in the near future to assist in the compositional analysis of the inactive materials (dust particles) with which the radioactive particles are associated.

2. 3. 3. Mine Environmental Control Program

In general, the objectives of the environmental control program are to develop accurate and meaningful

Assess health hazard

methods of assessing the health hazard present in a mine environment and to determine the effectiveness of control systems used in mines to reduce these hazards. More specifically, the work to date at the Elliot Lake Laboratory has been concerned mainly with:

(i) the comparison of dust sampling systems in artifically controlled dust clouds of known characteristics;

(ii) the feasibility of reducing concentrations of respirable radioactive dust by filtration methods;

(iii) the design and calibration of new and special purpose sampling systems.

(i) Comparative Tests

Mine dust sampling studies

Six single-parameter sampling systems made up of eleven sampling instruments commonly used in and about mines have been compared in some 125 dust clouds prepared from six test materials (pure minerals and glass fibre). A detailed analysis of the 7,000-data results have been made. The results indicate that depending on the sampling systems compared the estimate of relative dust concentration may vary as much as 20 to 1. Some of the variability rests with the design of the instruments and others with the changing properties of the dust cloud - size distribution, aggregation, density, shape, optical properties. It is apparent that no predictable relationship exists between the health hazard and the dust concentration estimated by most single-parameter systems now in use even after allowing for compositional effects.

Gravimetric sampler looks good so far

Further studies showed that the gravimetric samplers fitted with size selectors gave reasonably good correlation in dust clouds prepared from one type of rock. It remains to be proven that such evaluation in terms of mass can be related to the health hazard and that this system of sampling is applicable to the wide range of conditions found in Canadian mines.

(ii) Filtration of Radioactive Dusts

The method of reducing the concentration of dust in mine air by dilution is becoming more and more costly as mine workings become more extensive and allowable threshold limits become lower. In uranium mines where the contaminant is a radioactive dust, other methods of reducing the concentration of the airborne dust must be considered. The radiochemistry laboratory is primarily concerned with the study of radon daughters in the ventilating air in uranium mines, particularly with their source, build-up rate, amount and distribution (in relation to the airborne dust) as well as practical methods for their removal or control.

MRC filter tests

A filter test unit designed and fabricated at the laboratory has been set up underground in a uranium mine. A series of make-up and commercial filters have been tested and others are being prepared for testing.

The tests on the fine sand filter media have been completed. These tests indicate that the sandbeds are reasonably efficient for the removal of total and respirable dust and radon daughters provided the flow rate through the filter is low (100 cfm). At high velocities, (300 cfm) the sandbeds fluidize and become less effective. It has been concluded that using this media would require unreasonably large cross-sectional areas for practical application.

Preliminary results on commercial filters reveal that the high efficiency filters are expensive and short-lived. Clogging is caused by carbonaceous materials such as diesel exhaust and premature failure by the effect of absorbed moisture on the strength of the filter fabric.

(iii) Special Studies

In addition and closely allied to the main research projects are short-term studies conducted on a co-operative basis with industrial and research associations.

MRC - industry studies

One such study conducted during the past year was a calibration check on a filter sampler used for monitoring the concentration of aluminum prophylaxis dispersed in mine changehouses. The tests showed the low optical density of the dust deposited on the filter paper and the variability of the light source used for evaluation purposes reduced the reliability of the instrument. Alternate methods of sampling were suggested.

UK and US studies

Two recommendations have been made for size-selector specifications for sampling respirable dust gravimetrically, one by the Medical Research Council, United Kingdom, and one by the U. S. Atomic Energy Commission. Some questions were being asked as to their correlation and interchangability. These selectors, the horizontal elutriator and the cyclone, were compared in 30 dust clouds of thirteen types prepared in the dust chamber. The results showed that both selectors gave the same mean estimate of the 'respirable' dust concentration by mass when the cyclone was operated at a sampling rate of 1. 4 litres per minute. Also, although size distribution within the dust cloud had an effect on the selectors, within the range of the dust clouds found in mines this factor causes less than 10% change in the respirable mass sampled by each.

2. 3. 4. Trends In Mining Research

For the non-toxic inert dusts, mass is an acceptable and measurable parameter and instruments are available to assess the dust hazard. Although size selectors are not as simple as the human lung, those available do approximate the sampling characteristics of the 'average' lung. Studies now must move into the field to establish the relationships between dust production and mining methods and to develop more effective control techniques.

The hazard index of a toxic dust cannot be determined by measuring a single parameter. Mineral components of toxic dusts will have to be studied to determine the contribution each makes to the hazard. The present studies on silica ores are concerned with

the breaking of rocks of known properties using a controlled breaking process - the impact tester - and comparing the mineral components of the dust, total and respirable, with that of the feed-rock.

The problem of radioactive dust clouds is a very complex and difficult one. The relationship between radon gas emmanation and the surface area of the exposed rock structures and the effects of stress on the rate of emmanation must be considered. The problems of inaccurate assessment and inadequate dilution must be overcome. Failing a breakthrough in more exotic methods of control such as filtration and freezing, the basic question to be answered is the right of miners to work in an 'unsafe' environment. It is possible the 'space-suit' miner or the 'rotating' miner is in the wings. Certainly the stringent legislation proposed in USA of 3.6 WLM (Working Level Months) per year should have a marked effect on the uranium mining industry in Canada.

2.4. Research on Mineral Processing

2.4.1. Crushing Operations in Metal Mines

Dust from crushing

The following notes on the problems of air pollution due to dust from metal-mine crushing plants assume that there is no question of politics or public relations involved, and that only a factual survey of the present situation is required from a technical viewpoint. Therefore, the answers to four questions were sought:

(a) What is a tolerable level?
(b) What is the level of present plant emission?
(c) What is the capability of available dust removal equipment?
(d) What research is necessary?

The problems of enforcement and incentives (which must also involve costs) cannot be considered until answers to the four basic technological questions are obtained.

(a) The tolerable level has never been determined accurately. Nevertheless, there are official opinions published which can be considered to have some scientific basis. From a public health standpoint the American Conference of Government Hygienists in 1955 proposed the following maximum concentration of mineral dusts in plant atmospheres above which workmen should not be subject to continued exposure for 8 hours a day for an indefinite number of years (threshold limit):[1]

Environmental air quality limits (U.S. source)

Asbestos (dust) 5 M. P.*/cu ft	= 177 particles/cc
Carborundum 50 M. P. /cu ft	= 1770 "
Portland Cement 50 M. P. /cu ft	= 1770 "
Silica Dust - above 50% free silica 5 M. P. /cu ft	= 177 "
Silica Dust - from 5 to 50% free silica 20 M. P. /cu ft	= 708 "
Silica Dust - below 5% free silica 50 M. P. /cu ft	=1770 "
Talc - 20 M. P. /cu ft	=708 "

It is stated in the report on dust conditions in British Columbia metalliferous mines[1] that "A figure of

* M. P. - Million particles

300 particles per c. c. has been chosen as an objective to work toward", and that "It is not known what concentration of silica dust is considered safe to breathe without producing silicosis".

R. Bainbridge of Wright Engineers Limited, [1] states that many urban areas require operating permits which specify in some instances that dust content of stack gas must not exceed 0. 4 grains per cu ft and that all dust in the 0. 5 to 5. 0 micron range can be considered a health hazard through lung damage.

J. H. McKibbon of Joy Manufacturing Company [2] gives as a possible future requirement "visually clear stack emission" equivalent to 0. 02 - 0. 05 grains per cu ft.

To reconcile these possible standards with the American Government Hygienists threshold limited, the shape and size of particles must be known. The following has been estimated for the threshold limit of +50% SiO_2 particles i. e., 5M. P. /cu ft:

Threshold limits (U.S. source)

1 um*	diam	qtz	spheres	= 0. 0001 gr/cu ft
2 um	"	"	"	= 0. 0008 gr/cu ft
5 um	"	"	"	= 0. 0140 gr/cu ft
10 um	"	"	"	= 0. 1070 gr/cu ft

(b) <u>The present levels of plant emission</u> are difficult to ascertain. At dust control pickup velocities being used at present the air loading can be as high as 5-10 grains per cu ft. Efficiency of air cleaning equipment varies from nothing to complete depending on particle size. Actual efficiencies (as opposed to manufacturers claims) are hard to find but the Cottrell type precipitators at the Stelco Sinter Plant are reported as being 99. 4% efficient with an outlet gas content of 0. 03 gr/cu ft.

Dust in plant ventilation systems

The scrubbers on the final stack at Carol Lake Iron Ore Co. of Canada, give an outlet gas content of 0. 02 gr/cu ft. This is actually a visually clear stack and confirms McKibbons range of 0. 02 - 0. 05 gr/cu ft. An estimate of particle count would be about double the American Government Hygienists threshold of 5 M. P. /cu ft for silica dust but below the 20 M. P. /cu ft threshold for

Carol Lake gas scrubbers

*um - micron

dust less than 50% silica. (The actual mineral or chemical content is not known).

Air re-circulation

The amount of air released to atmosphere varies from plant to plant. A great deal of air is recycled to conserve building heat and to obtain maximum product return. At Iron Ore Company less than 1% of the air is bled off the circulating system.

British Columbia improved air quality 100%

Naturally, the quality of air retained in the plant is very important. Although in-plant hygiene is not within the terms of reference of this report, the air quality in the crushing plants in British Columbia mills improved by 100 per cent from 1937 to 1960, and therefore similar improvement is possible if the same equipment is used on released air.

Commercial dust separators effective

(c) Manufacturers brochures are the best source of information on equipment capability. Although performance estimates are not too reliable on plant fumes, etc., the manufacturer's data is considered quite reliable on rock dust. McKibbon[2] states that, with normal dust loadings of 5-10 grains /cu ft, Cottrells or filters can be relied upon to give efficiencies of 99.0% or better with results in the 0.02 to 0.05 grains /cu ft range. The scrubber equipment at Carol Lake has demonstrated a 0.02 grain /cu ft performance.[3] Cottrells at Stelco and Noranda have demonstrated 99.4 and 99.86% efficiency respectively.[2]

Research needed on tolerance levels

(d) Research is necessary mainly to determine the tolerance levels which can reasonably be imposed on industry. The improvement in dust removal equipment is principally an engineering challenge so should be done by the industry. It is doubtful if much could be accomplished at the Mines Branch in this regard.

Mines Branch interest in dust disposal

What is probably more important for Mines Branch research is the ultimate disposal of the dust collected. If collected wet the dust becomes a water pollution problem. If collected dry it becomes a

Research on water cleaning

solid-waste disposal problem. These problems require a great deal of research and work has already been started on research on waste water cleaning and recirculation and on solid waste reuse and disposal in the Mineral Processing Division.

References

(1) R. Bainbridge, Dust Control and The Design Engineer in the Mineral Industry, Paper presented to CIM, April 1962.

(2) J. H. McKibbon, Developments in Dust Collection Equipment. Paper presented to CIM, April 1962.

(3) C. Murphy, Chief Metallurgist, Carol Lake Mines, private communication.

2. 4. 2. Comminution of Non-Metallic Minerals

Dust removal systems not suited to some drilling operations, but good in most plants

With the exception of the asbestos industry, there is little in the way of adequate dust removal systems in the processing plants. Most of these minerals are dry quarried; rotary-percussion drills are operating without dust-collecting devices; dust control within the plant is often vented through a short stack to the outside atmosphere. The present technology is sufficiently developed whereby this situation could be remedied. In our largest asbestos processing plant the control of environment is excellent; in fact, dust counts reveal less particulate material than exists in the outside air around the plant. This particular operation circulates 2-1/2 million cubic feet of air per minute, which passes through bag chambers for removal of the particulates by the cloth-filtering media. It would seem to us that in the non-metallic industries the problem is known, the technology for the solution is also known, and the major factor against implementing this technology is an economic one.

2. 4. 3. Calcination

A few years ago, President Johnson of the U. S. A. called together an advisory panel under his Scientific Advisory Committee to report on the environment.

U.S. concern about CO_2 accumulation

The report made very clear that the major long-term problem facing air quality was the increasing accumulation of CO_2 in the atmosphere. It pointed out that the present rate of emission was in the order of six billion tons per annum, and that by the year 2000 there will be an increase of 25% in the CO_2 content of the atmosphere, since more than one-half the CO_2 emitted remains in the atmosphere.

Calcination produces 10 million tons CO_2 per year in Canada

The cement and lime industries are Canada's largest examples of calcination. At current levels of production, together they contribute ten million tons of CO_2 to the atmosphere annually. 65% of this results from the dissociation of limestone. Because of the modern uses of lime, a negligible amount of CO_2 is removed from the atmosphere in recarbonation of the products of these industries. As far as we are aware, there is no practical solution on the horizon for this problem.

Cement industry uses dust separators

The same industries also contribute particulate material to the environment through stack gases and from other phases of their operations. While dust precipitation is practised by the cement industry, there is very little practised by the lime industry. It is interesting to note that in the United States the cement and lime industries are among the major industries that will soon be subjected to uniform emission control standards under the U.S. Air Quality Act.

2. 5. Research on Hydrometallurgy

Many hydrometallurgical operations in Canada do not contribute significantly to air pollution. These include the Bayer process for aluminum. The cyanide process for gold ores, and both the acid and alkaline leaching processes for uranium ores.

SO_2 main pollution

The principal pollutant is sulphur dioxide, which is liberated daily in high tonnages to the atmosphere due to the roasting or smelting of sulphide ores of copper, nickel, lead and zinc. Fuel waste gas typically contains 0. 1 - 0. 3 per cent sulphur dioxide compared to 2 - 8 per cent sulphur dioxide in metallurgical waste gas. Although some of the latter gas is treated to recover sulphuric acid, handling and transportation problems limit the amount that can be used. In addition, the fertilizer industry, the largest consumer of sulphuric acid, can only expand slowly in the near future.

Metallurgical waste gases

When the compositions of the fuel and metallurgical waste gases are compared, it is evident that with the exception of differences in the composition of SO_2 , the gases are essentially the same from a chemical point of view. From an engineering standpoint they differ in the amount and nature of the particulates they carry and in the constancy of the SO_2 level over a period of time. Fuel waste gases are reasonably constant in their composition, but metallurgical gas compositions vary with the stage of the process from which they are liberated. It is significant to note that despite the engineering differences, any process developed to cope with one type of gas might well be able to contribute to the abatement procedures for the other.

The progress in North American efforts on pollution abatement may be considered within the context of a time frame. There are:

Additives

Temporary Measures that will cope with the immediate reduction in SO_2 levels by the wasteful procedure of combining it with other

materials to make a very stable compound for discard. (Limestone injections to heating boilers fall in this category)

Intermediate Measures that will permit the efficient concentration of the SO_2 for later conversion to sulphur or a marketable sulphur product. (This category includes most of the catalysts and adsorbents that have been considered, e.g., the U.S. Bureau of Mines alkalized alumina process and the new Babcock-Wilcox process)

SO_2 recovery processes being developed

and:

Long-Term Measures that will foster those process changes in the fuels and metallurgy industries that will no longer make it necessary to generate and waste sulphur dioxide. (In this group it is interesting to think of fluidizing coal with lime to gasify it and to immobilize the sulphur prior to combustion, and also, to think of roasting processes that do not produce sulphur in an oxidized form i.e. S or H_2S)

New processes to eliminate problem

We feel that the Mines Branch has the capability of working effectively in each of these areas. We favor the encouragement of that work, because if we cannot help the metallurgical and fuels industry in maintaining their competitive world positions, we will be in danger of losing at least part of our nickel industry to other countries where lateritic ores occur and can be processed without generating significant pollution.

Lateritic ore competition

At the present time we have small active research and development projects operating in the Temporary, Intermediate and Long-Term time frames. Our Temporary Measure projects include studies of the reasons why limestone injection is never over 30% effective in removing SO_2 from stack gases. This involves a detailed study of the reaction to determine whether it is a matter of insufficient time, incorrect temperature or protective coatings or sintering that is preventing the utilization of 70% of the material. In additional, individual limestones and dolomites behave differently. We are attempting to develop small-scale

Limestone injection studies

tests that will correlate and predict actual boiler tube behaviour of some typical Ontario limestones and dolomites. This work is being done in co-operation with Ontario Hydro.

In the area of Intermediate Measures we have an active project underway for assessing those oxide systems that can be used most effectively for trapping sulphur dioxide and converting it temporarily to a sulphate that can later be regenerated to the oxide and elemental sulphur. A computer terminal and measured experimental data are being used to assess the SO_2 levels that could exist in equilibrium with various oxides at different temperatures.

Computer program

Our principal project in the Long-Term Measures category involves the development of a process for producing elemental sulphur from sulphide minerals. We believe that sulphur is the only reasonable product to produce in quantity, and that any new process that is developed must be compatible with those currently used processes that produce sulphur dioxide. We believe that sulphur dioxide will continue to be produced for some time by metallurgical processes, and that a phasing-out and -in of processes can best be accomplished if the old and new processes are compatible.

New process to produce S from sulphide ore needed

Within that framework, the best choice would seem to be a process based on the generation of hydrogen sulphide. In the initial stages of the switch-over, the H_2S could be added to the present SO_2 gases, and elemental sulphur would be produced by a catalyzed reaction of the two gases. At later stages, when the SO_2 levels from current processes had decreased, some of the H_2S could be burned to make SO_2. In that way, the same process could be extended into the future.

2.6. Research on Physical Metallurgy

Rational approach to limits of abatement needed

As emission-abatement legislation demands increasingly more efficient collection systems, expenditures on pollution control devices will rise significantly, e.g., as compared with that required for 90% abatement, twice the expenditure would be required for 99% abatement and three times for 99.9% abatement. It is important to legislate wisely, taking into account topography, land use, climate and population concentration in order not to be unduly harsh on industry.

Metallurgy in-plant practices

"In plant" air pollution such as that associated with shakeout, mulling, cleaning, melting and pickling operations has been handled by installation of hoods, suction fans and other minor ventilation equipment, in most cases as a result of union insistence. Of course, if the pollutants are merely ejected through stacks into the atmosphere they simply add to the outside atmosphere pollution. This does not solve the problem, and simply makes it a matter of public concern.

Standard separation equipment used

Most air pollution abatement efforts to date have been directed to the installation of such equipment as electrostatic precipitators, bag houses, cyclones and scrubbers. Insufficient effort has been directed at the root cause of the pollution, namely the process itself. The type of approach that would appear to be the most likely to be profitable is exemplified by the U. S. Government-funded study by A. T. Kearney & Co. of Chicago on emission control in the iron foundry industry. The purpose of this work is the definition of specific research and development projects that will optimize control technologies to more effectively and economically control iron foundry emissions. Changes in furnace design, changes in emission control systems, and changes in operating practice will be considered.

The following submissions outline the problem areas in the ferrous metals industry and the current state-of-the-art with regard to pollution abatement. It is felt that the Mines Branch might be able to look at some limited aspects of the melting operations in the ferrous area with a view to changing the operating practice so that the amount of pollution will be minimized.

2.6.1. Ferrous Foundry Pollution

The principal source of pollution in ferrous foundries is the melting operation. For the most part the cupola furnace is employed by cast iron producers, and the electric arc furnace is used most widely in steel foundries.

Cupola widely used in grey iron foundries
Only few in U.S. use control systems

No Canadian statistics are readily available to indicate the numbers of grey iron foundries using air pollution control equipment. In the United States 90% of the cast iron producers use the cupola as their source of molten metal. Only one out of seven of U.S. grey iron foundries has air pollution control equipment: for those with annual sales under $1 million only 5% have control, as compared with 30% of the larger plants. Of those with air pollution control, one half use the "wet cap" system. The majority of the arc furnace operators with air pollution control favour the bag house (fabric filter) system.

Cupola emits 5 to 45 lb/ton/hr

It is reported that from 5 to 45 lb/ton/hr of particulate emission can be expected from a cupola. One factor which can have a pronounced effect on the volume of emission is the size of the charging door, due to indrafts. Data for two similar 48 in. diameter cupolas, with door areas of 46 sq. ft. and 12.6 sq. ft. showed emission volumes of 20,570 cfm and 15,600 cfm, respectively. The emission from the cupola with the larger door contained 1.11 gr/cu. ft. particulate matter, whereas the other emission had only 0.798 gr/cu. ft. particulate matter.

Cupola door area effect

Ontario regulations favour small cupolas

The majority of the approximately 300 cupolas in Canada are involved with small foundries. In Ontario at least, the existing air pollution regulations for ferrous foundries favour operations with cupolas producing less than ten tons of iron per hour, allowing a maximum of 75 pounds per hour of particulate, as compared with an allowed particulate emission of 25 pounds per hour for those cupolas producing more than 10 tons per hour. (The two examples cited above show emission of 196 and 107 lb/hr). Hence, for the small foundry relatively inefficient

control equipment is sufficient to ensure compliance with regulation.

The quantity of emissions from electric arc furnaces is similar to that from the cupola, of the order of 10 to 30 lb/ton/hr. However, the particulate size tends to be finer, being essentially micron and sub-micron sized metallic oxide particles.

Flaven furnace promising to reduce pollution

A recently designed Belgian iron melting furnace, called the Flaven furnace, utilizes the counter current efficiency of the cupola, coupled with the temperature and compositional control advantages of reverberatory furnaces. The fume emission is reportedly significantly smaller, and it is anticipated that the cost of such a furnace would be much lower than electric arc or induction melting units.

Much of the current literature on air pollution control is centered on the effectiveness of various devices. Some indication of the variation in price and effectiveness of various control installations is given by Table 1.

TABLE 1

Performance Range of Cupola Collectors and Approximate Cost of Equipment for a 12 ton/hr Cupola

Collector Type	Effective on Particles Over:-	Approximate Cost
Wet Cap	44 microns	$30,000
Dry Centrifugal	10 microns	$60,000
Med. Pressure, Wet	3 microns	$90,000
High Temp Fabric	0.2 microns	$150,000
High Energy, Wet	0.5 microns	$170,000

In deciding to implement air pollution control, cupola operators face an economic disadvantage in that the cost of efficient control equipment as a percentage of base equipment cost is extremely high due to the large gas volumes, the need to incinerate unburned oil and burn carbon monoxide, the high temperature of the gases and high engineering and fabrication costs.

Electric arc furnace fumeless studies

The Mines Branch should be able to make a significant contribution to the study of "fumeless" refining in the electric arc furnace (simultaneous injection of oxygen with either fuel oil, methane or natural gas onto the bath). More work is required in this area on the evaluation of reaction rates, optimum gas mixtures, temperature of exit gases, hydrogen pick-up in the metal, as well as method of introduction. Similar investigations related to basic oxygen furnace practice might be carried out with certain equipment modifications.

Possible improvements to the cupola

Presuming the availability of a cupola, there are a number of approaches to reducing air pollution which could be investigated. It is reported that fumes are reduced when natural gas is employed, and the use of natural gas injection to replace a portion of the coke normally employed should be further explored. Suggested designs and new designs to reduce the indraft at cupola charging doors should be evaluated. The use of recuperators to use waste heat of the gases in cupolas is relatively well established, and is useful only in quite large installations. Afterburners are not as widely used in small cupolas as they might be, and work in this area could be useful.

2.6.2. Air Pollution in Steelworks

Air pollution abatement in the steel industry has been generally limited to the removal of metallurgical dust from stack effluents. While the concern here is with air pollution, it should be recognized that air and water pollution are interconnected in that most of the water pollution problems of the steel industry come from the control of air pollution. A blast furnace producing 1000 tons of pig iron a day requires about 11 million gallons of cooling water a day. Similarly, about 20,000 gallons of water are used in the production of one ton of steel.

Blast furnace pollution

The current discussion will be restricted to air pollution control as related to steelmaking processes, and primarily to open-hearth and basic oxygen furnace (BOF) practice.

Particulate matter makes up the steel industry's biggest pollution problem. Carbon monoxide, oxides of sulphur, oxides of nitrogen and hydrocarbons are harmful pollutants in low concentrations. However, with a suitable gas cleaning system the content of these pollutants in a steelworks' emission can easily be kept below the level associated with harmful effects.

Canada follows U.S. practices

While reliable Canadian statistics are not available, U.S. statistics might be considered to be somewhat indicative of at least the iron and steelmaking core of Canada, centered around Hamilton and Sault Ste. Marie, where 85% of Canada's iron and steel tonnage is produced. According to one 1968 report a total of 11 million tons of particulate matter is discharged into U.S. skies each year from all sources. About 6 million tons comes from industrial plants and operations. Another source has indicated that in the same period the steelmaking industry would generate about 2 million tons of particulate matter. In Canada it is estimated that on the basis of 1968 production about 220,000 tons of particulates were generated by the iron and steel industry.

Dust from open-hearth, Oxygen lancing, B.O.F.

The average dust loading or emission from an open-hearth furnace without oxygen lancing can be about 4 to 10 pounds per ton of steel. Oxygen lancing considerably aggravates the problem of combatting air pollution, resulting in total particulate emission between 10 to 30 pounds per ton of steel, and peak dust loadings as high as 6 gr/cu. ft. No precise figures are available for total dust loading from the basic oxygen furnace, but it is reported variously between 12 to 40 pounds per ton of steel made.

With the increased use of oxygen lancing in the open-hearth (in the U.S. in 1968 over 50 per cent of open-hearth furnaces were so equipped) and with the increasing trend towards replacing standard open-hearth furnaces with basic oxygen furnaces, an increasing number of more

More efficient gas cleaning needed for oxygen lancing

efficient gas cleaning plants and particulate matter removing equipment will be required by the steel industry in the years ahead. Canadian steel producers foresee a drop of 40 per cent in open-hearth capacity by 1975 (from 5.9 to 3.8 million tons), and a concomitant increase of about 200 per cent in the BOF capacity (from 3.3 to 9.7 million tons).

Standard dust separators

The science and technology of electrostatic precipitation are well advanced and have been documented extensively. Fine dusts below 0.5 micron can be collected by commercial water scrubbers and bag filters. Thus, means are available to collect almost any particulate matter discharged in an iron and steel industry environment.

economics

The economics of dust removal are strongly influenced by the standards that have to be met. A gas with a residual dust loading of 0.05 gr/cu. ft. is marginal, and at times the stack discharge would be coloured. To eliminate visible discharge at all times the loading should be limited to 0.03 gr/cu. ft. It must be recognized, however, that to achieve this small improvement the workload of the cleaning system would be increased by about 33 per cent.

The factors affecting the decision in favour of a particular system include installation and operating expense, the efficiency requirement of the system, and local conditions such as availability of an adequate water supply, room on site, governmental regulations, and manner of dust utilization.

Cost of installations

In view of the high cost of gas cleaning equipment, it is possible that even a large integrated iron and steelworks may find its installation and maintenance financially difficult. Whichever cleaning system is selected, it will represent a substantial portion of the capital cost of the steelmaking plant. For example, a new BOF shop at Bethlehem Steel will incorporate $5 million in air and water pollution control. Nevertheless, the abolition of a social evil such as atmospheric pollution should not be reckoned solely in terms of money spent on control measures. The total annual cost of air pollution in the U.K. several years ago was estimated at $700 million. According to a recent report the total annual pollution

damage within the U. S. A. is more than $12 billion, representing a per capita cost of $65 per year. Granted that such estimates probably do not have a rigorously firm foundation, nevertheless they do serve to put the problem into true perspective.

To prevent pollution, the iron and steel industry must expend large sums of money annually. American iron and steel companies have committed $327 million for environmental quality control expenditure in 1969 and later. Of this total about $155 million will be provided for air pollution control, as compared with $37. 5 million, $39. 5 million and $40 million spent in 1966, 1967 and 1968, respectively. The net result of the $900 million spent by the U. S. iron and steelmaking industry on pollution control since 1951 is that more than 75 per cent of steelmaking furnaces have been equipped with gas cleaning systems, and another 50 per cent of air-water pollution problems have been overcome.

$96 million being spent by Canadian industry

In Canada, DOFASCO recently announced a $28 million anti-pollution program to be conducted over the next six years. STELCO and ALGOMA also announced a spending program of $68 million that would virtually end pollution in these plants.

Rational approach needed

The high cost to the iron and steel industry of combatting pollution may add to the cost of the product, and this consideration together with its effect on developing a viable export market, especially in Latin America, should always be borne in mind. The industry for its part would hope that the regulations governing now and in the future will not be dictated by abstract ideas based on results that may often be imprecise, e. g., inadequate scientific knowledge of the effect of pollutant matter and of the maximum allowable concentrations in the air, of the way in which emissions spread, the role played by natural phenomena, and the difficulty of obtaining representative samples of fumes and dust loadings.

2. 6. 3. Non-Ferrous Metals

The products and processes involved in air pollution by non-ferrous plants vary widely, and it is difficult to estimate in general terms the contribution they make to

the total air pollution in Canada. The problems are, in many cases, the same as those of the smelters, discussed by the earlier speakers. For this presentation the problem of air pollution has been treated in terms of specific pollutants such as products of combustion, chlorine, fluorides and so on.

(a) Products of Combustion - These are common to almost all metal fabricating processes, especially melting. In the non-ferrous industry, reverberatory furnaces are most commonly used, and these have the twin disadvantage of low thermal efficiency, and high exit gas temperature. In reverberatory furnaces, the products of combustion usually contain entrained particulates, such as aluminum chloride, as well as volatile materials such as zinc vapour, and therefore must be cleaned.

Reducing emissions from non-ferrous melting

Since the cost of effluent treatment is largely a function of the volume of gas to be treated, it is apparent that increasing the efficiency of the melting units should be attractive in terms of general economics, reduction of the volume of gas to be treated, and reduction in the combustion products discharged. It is suggested, therefore, that the Branch should give some thought to this as a subject for research as it has the advantage of being applicable to a wide spectrum of metallurgical processes. The recently introduced Asarco shaft furnace in which copper cathodes are melted to tough pitch copper is an excellent example of the economies to be gained from the replacement of reverberatory furnaces.

(b) Chlorine - This gas probably represents the most obvious pollution hazard in the non-ferrous industry. It is used in the aluminum industry for: (i) cleaning melts of oxide and dross by the formation and agglomeration of chloride particles, (ii) degassing melts either by the formation of hydrogen chloride or the mechanical entrainment of hydrogen diffusing into chloride bubbles, and (iii) removing magnesium, as magnesium chloride, from secondary scrap melts so that these will meet the chemical composition specification. All these are accomplished by bubbling chlorine through the melt and the products (pollutants) are, variously, excess chlorine,

hydrogen chloride, volatile aluminum chloride and, solid or liquid, magnesium chloride. With the exception of primary aluminum producers, most plants are located in industrial or urban areas, and the effluent must be collected and scrubbed.

100 tons chlorine used per year

The estimated consumption of chlorine for the purposes outlined above is about 100 tons per annum, but, because of some reluctance on the part of the industry to admit to the extensive use of chlorine, it is possible that the actual figures may be somewhat higher than 100 tons. As chlorine costs about $250 per ton, the total cost to the industry of $25,000 is not high, and great direct monetary savings cannot be anticipated by developing alternative processes.

Should seek substitute for chlorine

It is suggested that alternatives to chlorine could be sought in which chlorine is partially or completely replaced by other gases such as air or nitrogen. (Magnesium may be removed by oxidation and hydrogen will diffuse into, and be mechanically removed by other gases besides chlorine). Furthermore, it is suggested that chlorination could be carried out in "reactors" separate from the main bath. This would be expected to increase the efficiency of the reaction so that less chlorine is used, and no free chlorine is evolved. It would also considerably reduce the volume of effluent to be treated. It may be noted that the permitted concentrations of chlorine and hydrogen chloride are 0.1 and 0.04 ppm (vol.), respectively, for 30 min average at the point of impingement.

(c) Other Pollutants - Pollutants other than the products of combustion and chlorine, mentioned above, are:

Fluoride scrubbers used

(i) Fluorides - Fluoride fluxes are used in the light alloy industry, and together with oxides and volatiles are carried over by the furnace gases, making some form of scrubbing or filtration necessary. Although much work on fluxes has been carried out by various foundry supply companies, the use of fluorides persists.

(ii) Smoke - This arises from the melting of painted, oily or contaminated scrap in aluminum secondary smelters. Smoke generated is normally discharged into the reverberatory furnace stack, in the hope that it will be ignited by the high temperature. The problem of smoke is also common to other secondary treatment plants. In the case of copper wire, recovery poses a problem because of the increased use of chlorinated plastics as insulation, which generate HCl on combustion. In large plants the plastic and wire are separated by milling and cutting operations, both materials being re-used. Abatement would appear to rely on different furnace design, more pre-treatment, or more effective collection and treatment equipment.

Several methods used to consume and reduce smoke emission

(iii) Zinc Fume - Freshly-formed zinc oxide from brass melting operations is responsible for "zinc shake". Large plants use bag houses, smaller ones hood and vent, to reduce local concentration. Use of electric furnaces reduces the fume problem, and a better price for the bag house dust would make the use of bag houses more attractive. Currently, this is produced in Canada at the rate of 200 to 300 tons annually from secondary copper smelters, and is sold at about $50 per ton (5 cents per lb contained zinc) for concrete manufacture. The U. S. Bureau of Mines is working on alternative uses.

Recovered zinc oxide saleable by-product

(iv) Lead Products - Secondary lead smelters, battery plants, etc., generate lead oxide fume which is normally collected in bag houses and reprocessed.

(v) Sulphur Dioxide - This is evolved in magnesium casting and heat treatment operations where sulphur or sulphur dioxide is used to prevent burning. Often it contains other materials such as ammonium fluoride, calcium fluoride and various rare earths, thorium, and zinc chlorides which are used as fluxes or alloying additions. Present treatment is to collect fume by hoods to avoid local concentrations, and to disperse and dilute through the melting shop vents.

SO_2 dispersed

Alternative protective atmospheres such as CO_2, argon or SF_6 have been tried.

(vi) Ammonium Chloride - This is evolved in galvanizing operations, particularly the wet processes, when a cover of liquid zinc-ammonium chloride flux is maintained on the bath. It may be mixed with some HCl vapour arising from reaction with the flux, and $ZnCl_2$ and ZnO. In some processes ammonium chloride is dusted on the parts as they leave the bath, and this gives rise to dense fume evolution. Present treatment is to hood and vent. The problem is less severe in "dry galvanizing" when oxidation of the main body of the zinc bath is prevented by additions of small quantities of aluminum, and in continuous strip lines which are more easily enclosed.

(vii) Corrosive Mists - These are generated from a wide variety of processes such as pickling (HCl, H_2SO_4), anodizing and chemical milling (NaOH), and electroplating (H_2SO_4 and chromic acid). The problem is local health hazard rather than general atmospheric pollution.

Environmental problems

(viii) Oxides - Phosphorus pentoxide is evolved in quantity during the manufacture of Cu-15% P alloy used as a deoxidant in copper alloys. This alloy is now made by only one company in Canada, the fume being collected and wet scrubbed. Cadmium oxide is generated during the manufacture of cadmium copper alloy. Similar problems are encountered with selenium and tellerium. However, these are not large production items, and primarily a local problem treated by electric furnace melting and hooding.

Fruitful areas of research chlorine substitute

In summary, it appears that of the many pollution problems confronting the non-ferrous metals industry, the Mines Branch might make a useful contribution in at least two areas. The first, concerns the use of chlorine in the light-alloy industry where alternatives to chlorine, or more efficient use of chlorine in separate reaction chambers are suggested topics for research. The second area is in

Replace reverb. furnace

furnaces to replace the thermally inefficient reverberatory units now widely employed throughout the industry. This approach offers potential savings in terms of both fuel, and fume treatment costs.

Study fluxing reactions

Other possibilities are in a better understanding of the mechanism of a variety of fluxing reactions so that their efficiency could be improved and less toxic or less volatile compounds used. If any of the above research topics could be coupled with lower metal losses in the form of oxides, dross, or entrained metal, this would be an additional incentive.

2.7. Research on Metallurgical Coke

2.7.1. Metallurgical Coke and Air Pollution

At the present time commercial coke-making is confined almost solely to high temperature carbonization of coal in conventional slot-type coke ovens and it serves almost exclusively the needs of the integrated steel industry. Total plant capacity in Canada amounts to 8.9 million tons per year of coal.

The concentration of coke-making in Canada may be grouped approximately as follows:

Coke-making in Canada

Hamilton, Ontario	50 per cent
Sault Ste. Marie, Ontario	30 per cent
Sydney, Nova Scotia	10 per cent
Other	10 per cent

A major expansion of coke-making capacity occurred in 1967. However, the shortage of coke is again becoming acute and some Canadian plants are considering another expansion program.

It appears that the seriousness of the hazards associated with the coke industry is progressively increasing. For example, Reid and Buck reported in 1956 in the British Journal of Industrial Medicine that there was no excessive mortality rate among coke oven workers in the United Kingdom. However, Doll reported in the same Journal in 1965 that exposure to coal carbonization products could give rise to lung cancer, bronchitis, pneumoconiosis and cancer of the bladder. Statistics based on an eight year period with 11,500 men gave mortality rates of 17.2, 14.6 and 13.6 per 1,000 for workers with respectively decreasing concentrations of coke oven air pollutants. Incidentally, the overall average for all workers in England and Wales for the same period was 16.3 per 1,000. The Lloyd Report (USA) yet to be published "in toto" is said to be highly critical of industry. It is reported that the incidence of cancer in non-white workers in the coke oven industry is six times that of white workers -- the non-white worker job is generally more associated with areas with greater

Coke oven emissions harmful

tar vapour concentrations such as on top of the coke oven battery. One of the main health concerns is the carcinogenic effects of polycyclic hydrocarbon aromatics associated with the carbo-chemical aspects of carbonization. Some of these compounds are benzpyrene and pyrene, anthracene, chryprene and phenanthracene. The effects of coke oven tar containing 0.3% benzpyrene when applied to the skin of mice was demonstrated by Russian scientists in 1964. 150 mice were treated with the tar over a period of 7 months. At the end of this period 88 mice had developed malignant tumors. Normally the crude gas contains 334 mg/m^3 benzpyrene and this is removed with the tar during the scrubbing operation.

Carcinogenic compounds

Neglecting the preparation of coal at the mine source, there is a considerable amount of coal handling at the coke plant. This may comprise such operations as stock-piling, crushing, blending, coal conditioning for bulk density control, discharging from a central bunker into charging cars and the final feeding of the prepared coal into the coke ovens themselves. The product, namely coke, also contributes as a source of dust during discharge of the hot coke into the quench car, at the quenching station, during movement onto the wharf and the transfer to the screening plant, at the screen plant itself and finally during its movement to the blast furnace or alternatively into cars for transfer to other markets. Some dust also results from the waste gases from the battery waste heating system (50 mg/m^3).

Dust from coal and coke

It has been estimated that the total amount of dust admitted into the atmosphere from a plant with a coal consumption at 1000 tons/day is of the order of 150 Kg/hr. An investigation of three coke plants in England in 1964 concluded that, except in the immediate vicinity of the oven battery, the total solid disposition and the amount of smoke is less than in an average industrial centre and similar to a normal urban area. Also, that the total solids deposited was reduced by 50 per cent when an old battery was replaced by a new one.

The deposited and suspended dust around a coke plant may contain toxic material with carcinogenic effects principally 3, 4 benzpyrene. Jawata Iron and Steel in Japan have reported high concentrations near the coke oven batteries (150-300 mg/100m^3 in deposited matter). In

Pollution control measures effective

Czechoslovakia they report higher concentrations in the 2mm particle size (400 mg/100m^3). In one particular gas house in England it is reported that the 3, 4 benzpyrene was 200 mg/m^3 on top of the retort -- this value is approximately 100 times that reported for the city of London.

With regard to measures to reduce dust pollution, the Sovaco plant in France realized a reduction of 40 per cent in their coal preparation plant by the installation of dust extractors over the coal screens (initial count was 15 g/m^3/m).

In coke quenching, the Clairton Works of the U. S. Steel Corp. had an average of 6 pounds of coke dust (minus 200 mesh) discharged per quench. They have significantly reduced this amount by rearrangement of the baffles in the quench tower. It has been reported, in Czechoslovakia that the use of sulphite liquor in the quench water has reduced the amount of suspended solids in the vicinity of the tower -- only traces of SO_2 and H_2S noted in the atmosphere as a result of this practice.

Dust emission resulting from the filling of the larry cars with coal from a central storage bin has been reduced by a method proposed by Heinrich Koppers in Germany. A curtain of air surrounds the falling stream of coal and captures dust that otherwise would escape. Dust is removed in a scrubber and eventually re-introduced into the coal circuit.

Smokeless oven charging method effective

The main source of dangerous air pollution probably occurs during the oven charging operation. Fifteen to thirty tons of coal are dropped from a charging car (larry car) into a hot oven (2000°F plus). Coal dust, char, coke dust, products of complete and incomplete combustion and thermal distillation are given off in a comparatively short period. It is the tar vapour associated with this evolution, occurring mainly on the top of the oven battery, that has been made the main focus of attack by recent advocates of anti-pollution measures. There are several smokeless charging methods now in use to alleviate this problem. In general they consist of removing the dust and gases from around the charging holes. The gases are burned completely with the grit being

recovered, by sprays and the fine particles removed in cyclones. In Germany it is claimed that 95% of the dust hazard is eliminated; the escaping spent gases contain approximately 70 mg/m^3. The USSR have in use a system of preventing the escape of gas and dust during the coal levelling operation, which precedes the charging of the coal into the coke oven. Carl Still have also designed an oven to remove dust and gases from the top of the oven during charging.

Coke cars hooded

The coke discharge or the "pushing" of the coke from the oven is the most spectular aspect of carbonization from a layman's point of view. Ten to twenty tons of incandescent coke are dropped from a height of 20 feet into a car on rails which is immediately doused with a large volume of water. This procedure is completed in a matter of several minutes. One German coke plant has a hood covering the coke car and the coke guide which is connected in turn to the dust and gas extraction equipment located on the larry car. This removes a great deal of the dust and residual gas escaping from the discharging coke.

While the charging operation is probably the greatest contributer to serious air pollution, tap vapours and gases can be present in high concentrations in the immediate vicinity of the charging holes. The tar vapours at this point comprise a variety of hydrocarbon compounds which have undergone a wide range of pyrolysis. The maximum concentrations of noxious substances in the air are strictly defined in Russia and Czechoslovakia. Some comparative figures are given in the following table:

Maximum Permissible Concentration of Certain Toxic Substances

Substance	Concentrations in mg/m^3	
	Russia	Czechoslovakia
Ammonia	20	40
Hydrogen Sulphide	10	25
Sulphur Dioxide	10	25
Benzole	20	50
Phenol	5	30
Carbon Monoxide	20	36

The coke oven industry in North America is extremely conscious of the pollution aspect of its operation, particularly as a result of the recent Lloyd Report. The American Iron and Steel Institute (AISI) is spending large sums of money on research to develop ways and means of combating pollution. A smokeless charging technique is one known investigation currently underway; a new type of larry car has been designed and is under trial.

AISI Research objectives

A great deal of the air pollution comes from old coke ovens. Ovens in disrepair and old types of coke ovens using mudding techniques leak badly around the oven doors. The newer types of ovens have self-sealing doors with knife edge contacts. The Canadian ovens are in general, relatively new and in good condition. Some of the recently constructed coke oven batteries in Canada have provisions for smokeless charging techniques. One company has such equipment on order at a cost of 2 million dollars -- an indication of industrial cost of pollution abatement. In general the steel companies are considering the use of Burgess filter type masks for those men working on top of the oven batteries. It was recently announced that Stelco and Dofasco in Hamilton are to spend in the order of 45 and 25 million dollars respectively on anti-pollution measures. It is presumed that a great deal of this money will be directed to the coke oven pollutants.

Canadian ovens new - some have smokeless charging

There is little doubt that the conventional coke-making process will remain with us for sometime. Some plants are now contracting for expansion of their coke plants. However, it is visualized that the operating techniques will change with the demands of the steel industry. Increased productivity from the existing plants is mandatory. Canadian plants are operating at full capacity and will require supplementary coke shortly. Coal preheating techniques are a means of increasing the productivity up to 40 per cent from existing ovens -- one recently constructed battery of ovens in Canada has provisions for charging preheated coal. Most of the techniques suggested eliminate the larry car type of charging through charging holes on top of the ovens and provide a smokeless type of charge.

Oven expansion likely - will use new techniques

There has been a renewed interest in dry quenching of the coke to reduce the moisture in coke for blast furnace use.

Dry quenching

Such practice if adopted would reduce the pollution from coke dust.

Coal selection reduces pollution

Regarding the coal used for coke-making, tests at the Mines Branch have indicated that certain Canadian low volatile coals can be safely carbonized alone in slot-type coke ovens. The advantage of such practice of course is the high coke yields. The other accruing benefit could be approximately 12 per cent less volatile matter in the by-product with presumably a corresponding reduction in pollutants per unit of coal treated. Western Canadian coking coals also have the advantage of unusually low sulphur contents.

Form-coke process easier to control

There is no doubt that form-coking processes will eventually come into their own as a source of carbon to displace the conventionally produced coke; probably initially as supplementary coke. The methods of producing form-coke in general lend themselves to better control of air pollution.

Mines Branch model research facilities

The Mines Branch does have various pieces of equipment from laboratory-scale to pilot plant scale designed to evaluate the coking properties of coals. There is presently no relationship between the air pollution aspects of the technical-scale equipment and that of commercial coke plants. However, if necessary, the equipment could be modified to study specific conditions associated with air pollution from the carbonization of coal.

2. 7. 2. The Removal of Pyrite from Coal

Compound water cyclone used to reject pyrite from coal

An intensive investigation (begun at the bench-scale in the Ottawa laboratories and completed at the pilot scale in the Edmonton laboratories) demonstrated that the Compound Water Cyclone developed by Dr. Visman and his associates of the Western Regional Laboratory could be applied in an economic way to the problem of rejecting pyrite from coals. While this study was primarily directed to treating coals to be used for coking, the technique can equally well be applied to coals to be used for combustion (or other) purposes. Subsidiary problems with the analysis of coals for contained sulphur by type (organic, pyrite, etc.) arose and are being studied in the Ottawa laboratories with

the assistance of the Mineral Sciences Division. At the time of writing an industrial-scale proposal to use this separating process for the rejection of pyrite from Cape Breton coal at the production level of 1000 tons per hour is before the Cape Breton Development Corporation for application to the coal from the new Lingan Mine, now under development by the Corporation.

2. 7. 3. The Mechanical Dewatering of Coal

Dust control of fine coal

At first glance this development of oil-assisted mechanical dewatering processes to dispense with thermal drying is not directly related to air pollution problems. Thermal drying processes at coal cleaning plants are notorious in their production of dust, especially when treating coal with a high fraction of fines. The basis of the new process is the selective affinity of coal for oil in relation to water, which causes the water to be more readily displaced in mechanical equipment. Moreover, since in the new process, ultra-fine coal (-325 mesh) is mostly agglomerated and all the coal is oil-coated, there is a resistance to blowing out of rail cars in transit or from stockpiles. Indeed it is hoped that it will be possible to liberally water-spray stockpiled coal so-treated to avoid dust problems and yet not pick-up excessive water to hinder its further use. Freezing in coal cars is also resisted so that unloading can easily be carried out without the need for car shaking, another cause of dust at unloading points under winter conditions.

At the time of writing The Canmore Mines Ltd., is considering a unit of this type and it is hoped that the Cape Breton plant will also use this technique.

2. 7. 4. Need for New Coking Processes

Historically coke ovens are part of integrated steel plants (at least in North America) and most steel plants over the years have been hemmed-in by the cities (usually large) in which they are located. This writer believes it will be very difficult to operate coke ovens in city centres in such a way as not to be a nuisance, if not a hazard, even with the adoption of expensive available anti-pollution control measures. Hence, interest is

Continuous coking process

turning to new coking processes of a continuous nature that are inherently easier to operate with full pollution controls. This continuous type of process offers other advantages such as producing a coke of uniform size and the ability to use a wider range of coals. The coking process may be the first major industrial process in the minerals industry to have to be converted into an entirely new direction due mainly to the need to meet stringent pollution restrictions.

Relocation of coke processes

The location of the process (old or new) may also change. It is conceivable that restrictions at a remote mine site need not be those required at a city centre. This poses the problem of transporting coke - a low bulk density material (about 25 lb/cu. ft.) - where physical degradation would be a drawback. A "mixed" solution may be the most attractive: primary coking step at the mine with transport by train or pipeline followed by agglomeration at the consuming steel plant.

In summary, it can be said that not only are new processes for coking likely to be adopted but the geographical location of the industry may also change. Thus air pollution studies and transportation studies become related.

2.7.5. Air Pollution and Capital Requirements

As it has been a long-standing policy of all levels of government in Canada to seek to process mineral products to the greatest extent possible within Canada, it seems appropriate to comment on the effect of the need for anti-pollution. If we take as an example an industrial

Cost of pollution control

process with a capital requirement of $x per amount ton at a scale of operations A, then if the application of full control equipment doubles the unit capital requirement to $2x/annual ton (as it does with certain steel-making processes), the question arises as what increase of scale could overcome this disadvantage. Using the normal process engineering rule-of-thumb of the 0.6 power rule and letting y a be the new scale of operation with full pollution equipment yet the same unit capital cost as the original process, we have:

$$\frac{2x}{x} = \frac{y\ a}{a}^{0.6}$$

solving $y = 3.2$

Thus by increasing the scale of operations by a factor of 3.2, an equivalence of unit capital requirement is reached which nullifies the effect of the pollution control equipment on capital account. It must be recognized that Canadian processing industries are often at the limit of their scale due to the restricted market in Canada. In other words it may be easy for U.S. industry to up-scale because of their large market but not Canadian industry because of the small market. Moreover, interest rates are 10-15% lower in the U.S. as compared to Canada. In the coking industry there are signs, for example, of the formation of consortia of companies to build coking facilities of the new type in at least one major steelmaking center. Canadian companies might have to share in such a U.S. plant because it may be impossible for them to both develop the technical expertise needed for a new type of coking process and at the same time overcome the scale-of-operation problems. This presents a serious economic trap for Canada.

Cost of control greater burden to Canadian industry than U.S.

Despite this serious problem for Canadian industry, opportunities present themselves for Canada out of the need for improved environment control. To give an example, the agglomeration of iron ores is an important industry and there are two broad alternatives - ore sintering at steel plant sites or pelletizing at the mine or shipping sites. The technical use of sinter or pellets in the iron blast furnace is approximately equivalent. Because sinter plants are difficult to operate dust-free and even cause water pollution hazards (particularly arsenic in the water from the dust collectors), whereas pelletizing processes when properly operated at mine sites are acceptable, Canada gained a large, well-paying industry.

Ore pellets and sinter reduce dust - now an important Canadian industry

It is the writer's opinion that Canada should seek similar opportunities in the "further processing" field.

Site location and zone control

For other economic reasons there is pressure on many industries, notably steel, to locate their manufacturing facilities immediately adjacent to major market areas. The industrial flow-sheets of such industries should be carefully examined to see if Canadian locations at rail/water shipping inter-faces have unique advantages for the early stages of the industry. For example, it is difficult to believe "thermal" pollution of water need be a consideration at most Northern locations or that air pollution restrictions need be as rigorous as at the center of a major urban center. A clear definition of acceptable levels with zoning regulations to prevent housing from immediately surrounding processing plants should, in this view, be considered.

2.8. Research on Pyrometallurgy

2.8.1. Introduction

Mines Branch Pyrometallurgy research

Mines Branch has for the past couple of decades been pursuing research and development projects aimed at assisting those segments of the Canadian mineral industry where pyrometallurgical operations are involved. These projects have embraced both ferrous and non-ferrous metallurgy. In all cases the objective was the development of a new and better process, or the modifications or improvement of an existing process to make it adaptable to a different ore or raw material, and relatively little attention has been devoted thus far to air pollution problems associated with such processes. In a recent extensive program aimed at the development of a combined shaft-electric furnace, some limited studies were made of dust and fume evolved during the operation. These studies originated because for the first time we were operating a smelter where confinement of the off-gas was essential to the process. We were successful in doubling the throughput of the pilot plant smelting furnace when smelting iron oxide. Most of the energy required for this increased throughput was derived from the off-gas. This may prove to be a useful technique for at least partially paying the cost of air pollution control from electric smelting furnaces.

Recent publications [1, 2] indicate that there are some 70 odd pyrometallurgical plants in Canada in the primary iron and steel field, and some 35 to 40 in the field of non-ferrous and precious metals. Practically no quantitative information has been found in the literature regarding the magnitude of the air pollution problem created by these plants, or of the specific type of pollution generated by each. Nevertheless it is widely recognized that most if not all of these operations do contribute to air pollution. The types and amounts of pollutants will of course vary widely from plant to plant, but as a starting point for this discussion, it has been decided to classify them into three main groups -- dust, fume, and noxious gases. Although there is probably no clear distinction between "dust" and "fume"

which would be universally acceptable, we have chosen to use as a working definition the one given by R. A. Person[3], as follows:

-- "the term "dust" will be taken to mean solid particles that have resulted from comminution of larger solids, (dust would generally be greater than 2 microns in size); "fume" will be taken to mean solids that have resulted from condensation out of a gas phase, gas-phase reactions, or atomization of liquid, (fume would generally be less than 2 microns in size)".

2.8.2. Dust

Dust problem increasing

Dust is evolved at some stage or stages in practically all pyrometallurgical processes. The problem is probably increasing in severity with the passing of the years as the relatively high-grade lump ores become exhausted and the demand for the production of high-grade concentrates from low-grade ores has necessitated finer grinding for liberation of the minerals and their subsequent concentration. In iron production, the agglomeration by pelletizing has tended to counteract and alleviate this problem at the blast furnace, but in the non-ferrous industries large tonnages of very fine material have to be handled in the conventional processes which still account for the bulk of the non-ferrous metal production.

Pellets help

The technology required for removing dust (i.e. particulate matter $>$ 2 microns) from gas streams is available. In general, the difficulty of removing such dust from a gas stream is inversely proportional to the particle size, i.e., the difficulty increases as the particle size decreases. R. Bainbridge[4] presented information about dust and fume characteristics for various size ranges as follows:

Limits of dust separators

Size (microns)	Typical Material	Approx. Settling Rate (ft/min) in still air 70°F	Usual Collector
0.1	"Smoke"	0.00007	Electrostatic pre cipitator
0.5 to 5.0	Dust causing lung damage	0.002 to 0.148	Bag filters
10	Industrial dust	0.59	Wet scrubbers
50	Talcum powder	14.8	High efficiency centrifugal cleaner
75 to 100	Heavy industrial dust	59	Common cyclone

As the above table indicates, coarse dust has a relatively high settling rate, and is easily collected in a common cyclone. Some dust handling schemes use this settling property to remove the coarser dust from the gas stream, by providing an enlargement in the ductwork to lower the gas stream velocity and cause the coarser material to drop out before the gas passes to some collecting device[5].

2.8.3. Fume

Fumes are generated in most pyrometallurgical operations i.e. sintering, roasting and smelting. Anyone who has even driven past a ferrosilicon plant will be familiar with white cloud that is produced by this type of operation. Since ferroalloy production probably represents the greatest source of fumes within the pyrometallurgical industry, it deserves the earliest attention and the solution to the problems of this segment of the industry probably will provide answers for some other parts of the industry. The problem of controlling this fume has received considerable attention in several countries and a number of recent articles have been published[3-8].

Ferrosilicon plants worst offenders

Fumes are generated in the furnace and escape at the surface of the charge in open top furnaces. They are also generated when the furnace is tapped and when the metal is poured into moulds. In some operations where additional reactions are carried out in the ladles such as chlorination or oxidation, additional fumes are generated. In some furnaces, additional fumes are generated by baking of the Soderberg paste in the electrode columns.

Studies indicate that as much as 80% of this fume can be less than 0.1 micron in size. The bulk density of the collected fume is very low, varying between 4 and 30 lbs/cu ft when dry[3].

Good operation reduces pollution

The emission of fumes from a ferroalloy furnace can be lowered to some degree by good operating practice. Insufficient electrode submergence in the charge tends to produce additional fume. Moisture in the charge increases the volume of gas emitted by the furnace. This additional gas invariably carries additional fume. Incorrect electrode positioning can cause local hot spots which increase fume emission. Poor charge mixes can cause channeling and high velocity gas emission with entrainment of both fume and coarser dust. Under very poor operating conditions the fume emission can be 5 times higher than when the furnace is operating under optimum conditions.

Fume collection problems

The collection of these fumes presents a difficult problem, but it has been solved in a few plants. The collection system usually has to be a combination of several collecting methods. Heat exchangers or wet scrubbers usually are incorporated early in the circuit to cool the gas to a suitable temperature for the bag houses or other equipment which follows. Wet scrubbers to some degree simply transfer the problem from an air pollution problem to a water pollution problem.

Old plants greatest problem

The fume problem is more serious in older plants where the design of the building, furnaces and auxiliaries make it difficult to install adequate fume

collection equipment. It is probable that before the fume problem is completely solved most of these plants will have to be replaced and that older conventional furnace designs will be greatly altered.

2.8.4. Poisonous Gases

The two major poisonous gases emitted by the pyrometallurgical industries are carbon monoxide and sulphur dioxide. This list can be enlarged by considering other gases such as NO and arsenic trioxide, the latter one possibly being considered a fume.

Toxic gases

Very high concentrations of carbon monoxide are generated in some oxide smelting operations. Ferroalloy or pig iron production by electric smelting can produce concentrations of over 90% CO. In the past, with open top furnaces, these gases almost invariably ignited at the top of the charge and were not a poison hazard, but they often did produce undesirable heat concentrations above the furnace. In some of the more modern installations this CO is collected, scrubbed and used as a source of heat. The technology for collecting and utilizing this gas appears to be fairly well developed.

CO recovered and burned

Sulphur dioxide is the major gas phase evolved from the sintering, roasting and smelting of sulphide ores. Some of this SO_2 is collected and utilized for the production of sulphuric acid.

SO_2 recovery

The production of elemental sulphur rather than SO_2 at metallurgical plants is receiving some attention. In this connection, although INCO has not published many details concerning their new (IPC) process, one brief release indicates that one of their products will be sulfur.

2.8.5. Detection Methods

In general, dust sampling and detection equipment has been developed for the mining industry

rather than for the pyrometallurgical industries. However, this equipment should be interchangeable between the two industries. An excellent article in the October, 1969 issue of the CIM bulletin, by W. A. Bardswick and F. T. M. White[9] gives a fairly recent survey and assessment of the present state of dust detection techniques. They divide the dust sampling instruments into 5 general categories.

(a) filtration
(b) inertial
(c) thermal precipitation
(d) electrostatic precipitation
(e) light scattering

The recent development of a dual instrument incorporating thermal precipitation and light scattering techniques by the South African Chamber of Mines Research Laboratories suggests to the authors that this may lead to an international standard for assessing airborne suspensions. However, it appears that until the relationship between health hazards and particulate parameters of a dust cloud can be determined, the feasibility of establishing a precise international standard for dust hazard is remote.

In 1955 the American Conference of Government Hygienists adopted figures for the maximum concentrations of some common fumes and mineral dusts in plant atmospheres[4]. Although this table is no doubt outdated, it does give threshold concentration limits which should probably not be exceeded in modern day practice (see Table).

Environmental limits

TABLE

Arsine	.05 P. P. M.
Gasoline	500 "
Carbon Monoxide	100 "
Sulphuric Acid	1 mgs/cu metre
Arsenic (fume)	.5 "
Mercury (vapour)	0.1 "

TABLE (cont'd)

Lead (fume)	0.15 mgs/cu metre
Uranium (soluble)	0.05 "
Uranium (insoluble)	0.25 "
Asbestor (dust)	177 particles/cc
Carborundum	1770 "
Portland Cement	1770 "
Mica-above 5% free silica	708 "
Silica dust - above 50% free silica	177 "
Silica dust - from 5-50% "	708 "
Silica dust - below 5% "	1770 "
Talc	708 "

U.S. SO_2 and particulate limits in ambient air

In February, 1969, the U.S. Dept. of Health, Education and Welfare (HEW) issued air-quality criteria, covering sulphur oxides and particulates. They stated that adverse health effects may be caused by 0.1 ppm of sulphur oxides or 80 micrograms of particulates per cubic meter of air in the atmosphere over a 24-hr period[10].

U.S. methods of analysis

Non-dispersive infrared analyzers appear to be the most suitable for measuring sulphur dioxide content because they measure concentrations continously, are simple to operate and are reasonably inexpensive. Vapour phase chromatographs are used to analyze gas streams for SO_2, O_2 and CO_2.

The Los Angeles Air Pollution Control District (LAAPCD) has 12 monitoring stations presently gathering data on smog. It hopes to provide each of these stations with equipment to allow monitoring of ozone, CO, NO, NO_2, SO_2, methane, total hydrocarbon, temperature, humidity, wind speed and direction. This data will be telemetered to a central headquarters every twenty seconds for analysis on a computer and thus provide an up to date air-pollution record[11]. The experience and know-how realized from these efforts will undoubtedly be of aid in other fields.

2.8.6. Collection Equipment For Dust and Fume

Dust and fume separators Types and effiy

The dust and fume collectors have been divided into three major categories: (1) wet scrubbers, (2) electrostatic precipitators and (3) bag houses. The wet scrubbers include high energy or venturi type scrubbers as well as wet settling chambers. These wet scrubbers are capable of handling the higher temperature dust and fume emanating from pyrometallurgical equipment and in some cases represent a precleaning step of the dust-laden atmosphere. The venturi type wet scrubber (properly designed) has demonstrated collection efficiencies in the 98% range when used for collecting dust from a ferroalloy furnace. The electrostatic precipitator is capable of collecting large and small particles in a dry or wet atmosphere. It is also capable of operating at a higher maximum temperature than the existing bag filters. Electric furnace fumes have a high electrical resistivity and are not readily collectable in a dry electrostatic precipitator. This resistivity problem can be overcome by humidification of the gas stream and/or the addition of an ammonia conditioning agent. Collection efficiencies with electrostatic precipitators have been measured at greater than 95%. Bag houses probably have the highest collection efficiencies, but because of temperature limitations of approximately 500°F on the filter cloth (fibreglass), the furnace gases must often be cooled by heat transfer surfaces or dilution before entering the bag house. Filter bags must be cleaned and/or replaced on a routine basis in order to avoid dust leakages and in order to maintain uninterrupted service from the bag house the assembly has to be duplicated. In one case, a combination scrubber system which eliminated about 60% of the particulates and "wet" bag house system gave a virtually 100% elimination of the visible dust from a thermite smelting process[5]. Opinions have been advanced that the bag collector will probably function more satisfactorily in the ferroalloys industry as an air pollution control device than either the wet scrubber or the electrostatic precipitator[3, 12].

2. 8. 7. Collection of Sulphur Dioxide

The primary source of sulphur dioxide pollution in the U. S. A. is from power plants (about 54%) with about 10% from the smelting of ores. The total estimated emission of SO_2 for the U. S. A. in 1970 is 34. 2 million tons[13]. There appear to be 4 major processes under consideration in the U.S. A. for the "economic" recovery of SO_2 pollutant[13]. They are catalytic oxidation (producing 77% H_2SO_4), alkaline injection (producing gypsum), alkalized alumina (producing sulphur) and the Dry Char Absorption Process (producing 100% H_2SO_4). These processes will recover about 90% of the sulphur dioxide from the gas and essentially 100% of the particulate pollution.

SO_2 recovery

2. 8. 8. General Comments

The U. S. Health and Welfare department (HEW) has issued a statement claiming that particulates in an amount exceeding 80 micrograms per cubic meter may produce adverse health effects in particular segments of the population[10]. This figure would represent about 723 lb/mile^3 or 145, 000 short tons of particulates in a volume of space, 1 mile in depth, 100 miles in width and 4000 miles in length. If it is assumed that in the steel industry about 1-2% dust is produced per ton of steel[13], the Canadian steel production of 13 million tons per year would result in 130, 000-260, 000 tons of dust per year. Electrostatic dust collectors can readily collect about 99% of this dust[14], leaving approximately 1300 to 2600 tons of dust in the atmosphere. If this steel production is confined to a small area (such as it is in Canada) the production of dust will exceed the limits suggested by the U. S. Health and Welfare department.

80 reg/m^3 dust limit in air

Stack emissions that are visually clear require maximum outlet concentrations of . 02 to . 05 grains/cu ft[15] (approx 46, 000 to 115, 000 micrograms per cubic meter). Many metallurgical processes generate dust loadings in the range of 5 to 10 grains/cu ft, which will require dust recoveries exceeding 99% to be reduced to the non-visible range. These recoveries can be readily obtained through the use of electrostatic precipitators or bag

More than 99% dust removal needed

houses[15]. In order to reduce the .05 grains per cubic foot to below 80 micrograms per cubic meter, a further 99.9% of the dust must be removed. There is little doubt that this could be accomplished through natural settling of the heavier dust particulates and dilution with clean air, depending on the volume and kind of dust being emitted in a particular area. But in some cases it will require the use of a more highly efficient dust collector system (for example - a system collecting greater than 99.999% by weight of the dust generated). Baghouses have reported efficiencies of 99.9965%, by weight, on micronized talc with a mean particle size of 2 1/2 microns, but collection efficiencies for silica fume in the .01 to 0.6 micron range are only 99% by weight[12].

2.8.9. Conclusion

Literature review in progress

A literature survey concerning atmospheric pollution problems that are associated with pyrometallurgical industries has been commenced which should be of assistance in defining areas where the Branch can make use of its pyrometallurgical equipment and the training and experience of its members to contribute to the knowledge necessary for pollution abatement.

Abatement costly

The literature survey to date indicates that much of the technical knowledge necessary for cleaning waste gases from pyrometallurgical processes already exists, but the application of this knowledge will be expensive and difficult, particularly in older plants.

New processes through research

One area where the Branch can contribute in this regard is in research and development work on existing processes, and in searching for new processes, with the objective of minimizing the volume and/or dust loading of the waste gases produced by these processes. One such project in connection with electric furnaces is already in progress.

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2.9. Analytical Facilities

2.9.1. Mineral Sciences Services

The contribution of the Mineral Sciences Division at the seminar held on January 9th was limited to an outline of the analytical facilities that are available, and which could be called upon for support of programs in the field of pollution abatement of the Mines Branch as a whole. This support would primarily be concerned with characterizing particulate matter in terms of both physical properties and chemical composition. Because of the nature of pollutants in their many conditions of sampling, i.e., their extremely small particle size and the very limited quantities of such materials that may be made available for analysis, it is likely that some research or investigational effort would have to be made into suitable methods in order to provide accurate determinations. Listed below are the capabilities that the Mineral Sciences Division have available for such work, which also indicates the different types of approaches that might be used.

Characterizing particulates

1) Analytical Chemistry

In addition to the conventional volumetric and gravimetric methods that are now used only on special occasions, the following instrumentation is now in current use:

Analytical facilities

i) Polarography - - used for the determination of any organic or inorganic species capable of undergoing electrochemical reduction or oxidation. Analyses can be carried out very quickly and more than one element can be determined at the same time with a sensitivity of about one hundred times that of polarographs previously used.

ii) Atomic Absorption - - used for the determination of a large number of metallic elements. The instrument finds particular use in the determination of elements in the very low ranges of concentration, i.e., .01 to .1%.

iii) Spectrophotometry - - used primarily for a large number of elements as macro constituents in samples.

iv) Other special instrumentation is used for the determination of carbon and sulphur in very low ranges of concentration, i.e., down to .001%.

2) Spectrochemistry

i) Emission Spectroscopy - - five different emission spectrographs are available, which have their special fields of application. In addition, a new recording spectrometer has just been installed and is now operating, which has a vacuum path and is therefore applicable to all the light elements, that are not determinable by the conventional spectrograph. Sensitivities for emission spectrography run from between a very few parts per billion up to ten parts per million depending upon the elements.

ii) X-ray Spectrometry - - this is a 100 kV X-ray spectrograph used for non-destructive determination of elements, with a $\pm$ 2% precision of the amount present.

iii) Infrared Spectrometry - - a 2.5-50 micron range infra-red absorption spectrometer, used mainly for structure determination. However, it has some capabilities in quantitative work in the determination of such constituents as quartz and hydroxel groups in compounds.

iv) Neutron Activation Analysis - - this is a fast neutron generator with a flux density of 2×10^{11} and energy level of about 14 MEV. Its sensitivity is variable, depending upon the element but generally it requires a large

sample, i.e., 25 to 50 grams. It has special application for elements that are sometimes difficult to determine accurately by any other method, e.g., oxygen, hafnium, antimony and rhenium.

3) X-ray

There are six X-ray generators in the laboratory with a variety of cameras for powder work that can cover a range of temperatures and atmospheres. An extensive powder film library of about 35,000 films is currently on file, which probably represents the most extensive library of its kind in Canada, if not anywhere.

4) Surface Science

i) The capability of principal interest in this field is surface area measurements of which there are two different types of equipment:

(a) Krypton Gas Absorption - - capabilities exist to measure surface areas as low as .01 m^2/gr to within $\pm$ 1% experimental error.

(b) Perkin Elmer Sorptometer - - this is a more rapid method of making surface area measurements capable of measuring down to .05 m^2/gr but with less accuracy, i.e., $\pm$ 15% for low surface areas.

5) Radiation Measurements

Good facilities are available for making accurate and quick measurements of beta and gamma radiation over a spectrum of energy levels.

6) Optical Methods.

i) Microscopic equipment - - a variety of petrographic and ore microscopes are available for examination of powders for qualitative and quantitative determinations, and there is excellent photographic equipment available as attachments to record the characteristics of the materials being examined.

ii) Electronprobe microanalyser - - capable of dealing with all elements from atomic number 11 to atomic number 92. Sensitivity depends on element and matrix but is in the order of one part in 1,000 to 100,000.

In addition, there is a variety of other equipment that may be called into use from time to time, such as the Cahn Electro Balance whose maximum sensitivity is rated at .1 micrograms. It is possible to make a variety of magnetic measurements on various materials to determine their magnetic susceptibility permeability, etc. A research model Cary 14 recording spectrophotometer is in constant use for research and has a much broader wavelength spectrum than the spectrophotometers previously mentioned, i.e., from 1860 angstroms to .265 microns. It has unusually high resolving power and is equipped with optical instrumentation to examine materials at high magnifications and indifferent environmental conditions.

Special technique for mine dust

The Mineral Sciences Division has recently co-operated with the Mining Research Centre on a joint research project concerned with the quantitative X-ray determination of quartz and pyrite in mine dust. The technique used was developed by outside workers, but has been successfully applied and some improvements were achieved. The method provides reproducible analyses of quartz and pyrite in dust samples. When the calibration curves of the pure components have been made and certain sources of error are kept within appropriate limits, quartz and pyrite can be determined down to

30 micrograms per square centimetre when deposited on suitable filters.

The Mineral Sciences Division is primarily concerned with mineral raw materials, and less with the later stages of production where problems arise in the pollution field. However, a good deal of expertise has been developed and is available as the result of our investigations and research into the structure, properties and composition of materials of all kinds and this is available to any of the groups in the Mines Branch that are involved in the pollution abatement program.

2.9.2. Identification of Particulate Matter

The identification of solid particles gathered during a pollution program may have a great bearing on the extent of the control measures required. Evaluation of the hazards of the pollution being studied depends upon the ability to determine not only the chemical composition of the particulate matter but also to identify the actual compounds present. The identification method to be adopted depends on how large the sample is, how homogeneous it is, the size of the particles, and the levels of concentration that must be measured.

If examination under an optical or electron microscope shows that the sample is not homogeneous, attempts should be made to separate the particles into distinct groups. The sample, or fractions of the sample, should be analyzed by wet chemistry, optical spectroscopy, or X-ray fluorescence analysis, depending on the sample size, as early as possible in the investigation. Early fractionation and analysis may greatly simplify subsequent work using other techniques, e.g., knowledge of the elements present will make the analysis of X-ray diffraction patterns much less difficult.

X-ray diffraction techniques allow the reliable identification of compounds in samples in the order of a

milligram, but unless accurate lattice parameters are obtained it cannot be determined whether the minor elements are dissolved in them. Of course, the elements shown by analysis to be present in small amounts may exist in distinct compounds, but if their concentration is below 2 to 3 per cent they may very well be missed in a powder sample. These trace compounds may be the ones which are causing a very significant proportion of the pollution damage.

Optical microscope

If the analysis of the elements present shows a trace of a dangerous element or an element which often occurs in a dangerous compound, a search should be made under the microscope for a rare type particle distinguishable from the common particles by its colour or shape under an optical microscope, or by its shape under an ordinary electron microscope or a scanning electron microscope. The conventional electron microscope has the inherent advantage that electron diffraction can sometimes be made on a particle of interest of only 0.1-0.01 microns diameter. A chosen particle may be moved into position for diffraction while the equipment is operating as a microscope. The electron optics are then switched so that a very fine beam of electrons strikes that particle only and the resultant diffraction pattern is thrown onto a fluorescent screen and subsequently onto a photographic plate for recording purposes. The accuracy of lattice parameter measurements is less than that with X-rays, so that identification cannot be as certain. However, its unique ability to give data on a single fine particle makes the method very valuable.

Electron microscope

An extremely fine and intense beam of electrons may also be focussed on a particle in a scanning electron microscope. The Physical Metallurgy Division instrument is not as yet equipped with an X-ray spectrometer, but its installation would allow the determination of the analysis of elements present in a particle as small as 10^{-13} grams.

The electron probe microanalyzer may also be used for particle analysis but the light optical system

usually only runs as high as a few hundred magnifications so that very small particles of interest cannot be chosen for analysis. However, particles as small as 1 micron may be successfully analyzed.

X-ray fluorescence method

It is to be noted that X-rays have not been suggested for the analyses of very fine single particles, since X-rays cannot be focussed into an intense fine beam as can electrons. Furthermore, for fluorescent X-ray analysis, it is a fact that the intensity of the characteristic X-rays excited in the sample can only be brought up to measurable values by irradiating a large area if the element is present in trace amounts. Thus an average analysis of a large number of fine particles may be obtained by X-ray fluorescence. This may, in a sense, be an advantage because one may be tempted to spend much effort on the analysis of a single fine particle of doubtful significance rather than on a true sample containing millions of particles. The value of the whole effort depends on having representative, and hence, significant samples. The sensitivity of the X-ray fluorescence method can be about 1 ppm if the irradiated area is a few tenths of a square millimeter. This corresponds to about 10^{-8} grams.

The object of this presentation was to clarify the problems of identification of particles and to point out how well the Mines Branch laboratories are equipped to do this work. Obviously no one man nor single division can be competent to handle the great diversity of techniques available. The tabulation below shows the distribution of pertinent equipment within the Mines Branch.

Equipment	Mines Branch Unit
X-Ray Diffraction	Mineral Sciences Division. Physical Metallurgy Division Extraction Metallurgy Division. Mining Research Centre*, (Elliott Lake, Ontario).
X-Ray Fluorescence	Mineral Sciences Division. Physical Metallurgy Division.

Equipment	Mines Branch Unit
Electron Microscope	Fuels Research Centre. Physical Metallurgy Division.
Scanning Electron Microscope	Physical Metallurgy Division.
Electron Micro-Probe	Mineral Sciences Division. Physical Metallurgy Division.

2. 9. 3. Gas Analysis Facilities of the Petroleum and Natural Gas Laboratory

The gas analysis facilities required to study air pollution problems are quite diverse. On the one hand there is the special equipment required to evaluate the concentration of pollutants in smoke plumes, then there is the semi-automatic equipment for stack gas and automotive exhaust gas, finally there is the research gas analysis equipment for studying special problems. It is the last mentioned equipment we wish to briefly describe here.

Mass Spectrometer

There is available in the Fuels Research Centre a Consolidated Electrodynamics Model 21-104 Mass Spectrometer equipped with inlet systems for gases and liquids of low volatility, a direct insertion probe for solids and a gas chromatographic inlet. This equipment is useful for identifying trace quantities of pollutants that are difficult or impossible to identify by other means.

Chromatographs

Numerous gas chromatographs are available equipped with gas or liquid inlet systems and with a variety of dectors, including thermal conductivity, flame ionization, and flame photometric.

Microcoulometer

To estimate the quantity of nitrogen, sulphur and halogen compounds present at the sub-micro gram level a Dohrman microcoulometer is available.

For the precise estimation of the concentration of carbon monoxide at the levels commonly found in mines, a Wosthoff apparatus is used.

The above-mentioned analytical instruments are capable of detecting most of the common air pollutants in the parts per million range. With some modification it would be possible to increase the sensitivity substantially. This briefly summarizes the equipment that might be classed as research backup.

3. Ambient Air Quality Objectives

There are no national Standards for air quality, although a Canadian Standards Association Committee on Air Pollution Control has been re-activated after a period of assessment.

Without such standards, the Mines Branch has adopted the philosophy of protecting the atmosphere to the limit of contemporary technology. This is usually adequate to meet the most rigid international pollution abatement guide lines such as those being developed by OECD and by control regulations enforced by Provincial Authorities.

In Canada, the provinces of Ontario and Quebec seem to lead in this respect, although they have not yet developed a complete definition of ambient air quality. In developing such a standard, it is felt at the Mines Branch that the quality of air in a heavily industrialized area need not be the same as for parks and farms for example. Actually, it has been proposed that the zone classification first used in London, England, be adopted for use in Canada revised as follows:

Region A - Rural
Region B - Residential
Region C - Commercial
Region D - Industrial

A preliminary Mines Branch recommendation for ambient air objectives follows:

Table 1 - Recommended Ambient Air Objectives

	Region A	Region B	Region C	Region
Particulates				
Suspended (ug/m^3)				
24 hr sample				
50% of readings less than	40	55	80	135
84% of readings less than	60	85	120	200
Settleable ($mg/cm^2/mo$)				
30 day sample				
50% of readings less than	0.30	0.60	0.90	1.50
84% of readings less than	0.35	0.80	1.20	2.25
Gases and Vapours (Non Toxic)				
24 hr sample				
No more than 4 days per year may average, ppm	0.1	0.1	0.1	0.15
One hour peak, ppm	0.25	0.25	0.25	0.40

The following limits for specific pollutants have been suggested for Canada:

Sulphur dioxide	0.5 ppm for 1 hr 0.3 ppm for 6 hrs
Sulphuric acid (aerosol)	0.10 mg/m^3 (24 hrs)
Hydrogen sulphide	0.05 ppm for 1 hr
Ozone or oxidant	0.15 ppm for 1 hr or 0.05 ppm for 8 hrs
Nitrogen dioxide	-
Hydrogen chloride	-
Hydrogen fluoride	(30-50 ppm on dry wt in forage crops)
Chlorine	0.10 ppm for 1 hr
Ethylene	-
Carbon monoxide	-

Beryllium -

Lead -
Dust (inert) 0.2 mg/m^3

Fluorides as HF in air 1.0 ppb

According to the Financial Post (June 28/69, p. 3), the Ontario air management group defines when pollution begins as follows:

Table 2 - Concentrations Where Pollution Begins

Contaminant	Measurement of concentration	Amount of concentration at point of impingement	Period of time measured
Sulphur dioxide	Parts of sulphur dioxide per one million parts of air by volume	0.3	30-minute average
Suspended particulate	Micrograms of suspended particulate per cubic meter of air	200*	30-minute average
		100**	30-minute average
Dustfall	Tons of dustfall per square mile per month	15	One month
Carbon monoxide	Parts of carbon monoxide per one million parts of air by volume	5	30-minute average
Fluorides	Parts of fluorides per one billion parts of air by volume	10	30-minute average
Beryllium	Micrograms of beryllium per cubic meter of air	0.01	30-minute average
Lime	Micrograms of lime per cubic meter of air	20	30-minute average
Chlorine	Parts of chlorine per one million parts of air by volume	0.1	30-minute average
Hydrogen sulphide	Parts of hydrogen sulphide per one million parts of air by volume	0.03	30-minute average

* Industrial and commercial.
** Residential and rural.

Table 2 (cont'd)

Contaminant	Measurement of concentration	Amount of concentration at point of impingement	Period of time measured
Ammonia	Parts of ammonia per one million parts of air by volume	5	30-minute average
Carbon bisulphide	Parts of carbon bisulphide per one million parts of air by volume	0.15	30-minute average
Hydrogen chloride	Parts of hydrogen chloride per one million parts of air by volume	0.04	30-minute average
Lead	Micrograms of lead per cubic meter of air	20	30-minute average

Source : Ontario government.

In the United States, the probable safe limits for toxic pollutants have been proposed by the American Conference of Governmental Industrial Hygienists as follows:

Table 3 - Probable Safe Concentration Limits of Exposure for Toxic Dusts, Fumes, and Mists.

U. S. A.

Substances	Milligrams/meter^3
Antimony	0.5
Arsenic	0.5
Beryllium	0.002
Cadium	0.1
Chromium as Cr_2O_3	0.1
Fluorides	2.5
Iron Oxide fume	15

Table 3 (cont'd) [1]
U. S. A.

Substances	Milligrams/meter^3
Lead	0. 15
Magnesium Oxide fume	15
Manganese	6
Mercury	0. 1
Selenium	0. 1
Sulfuric Acid	1
Tellurium	0. 1
Zinc Oxide	15

[1]From the Committee on Threshold Limits, American Conference of Governmental Industrial Hygieneists. The Analytical Chemistry of Industrial Poisons, Hazards, and Solvents, M. B. Jacobs p. 766.

For control purposes one-third of the above concentrations should be used as the upper limits.

Using these guidelines from Ontario and the United States, the Mines Branch should:

(1) Select the guideline concentration appropriate for a given mineral, metallurgical, or combustion process
(2) Determine how to obtain the maximum reduction in emission of pollutants within the limits of the operating controls of the process
(3) Within the economic limits of the process, demonstrate how to reduce the resulting pollutant concentration (eg. by gas scrubbing)
(4) For the remaining pollutants, use developed chimney - height standards to determine an adequate stack.

While applying this known technology, research continues that, hopefully, will continully reduce pollutants at the source and possibly alter their physical and chemical properties so that they will be harmless when emitted to the atmosphere.